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USER'S GUIDE FOR THE CLIMATOLOGICAL DISPERSION MODEL

NATIONAL ENVIRONMENTAL RESEARCH CENTER

DECEMBER 1973

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CLIMATOLOGICAL DISPERSION MODEL

by

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National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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PREFACE

This report provides information on and the computer program for the Climatological Dispersion Model (CDM). Although the computer program was formulated and tested with care, it is possible that some forms of valid input data were not adequately tested.

In case there is a need to correct, revise, or update this model, revisions will be distributed in the same manner as this report. If your copy was obtained by purchase or through special order, you may obtain the revisions as they are issued by completing the mailing form below.

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ABSTRACT

The Climatological Dispersion Model (CDM) determines long-term (seasonal or annual) quasi-stable pollutant concentrations at any ground-level receptor using average emission rates from point and area sources and a joint frequency distribution of wind direction, wind speed, and stability for the same period.

This model differs from the Air Quality Display Model (AQDM) primarily in the way in which concentrations are determined from area sources and in the use in the CDM of Briggs' plume rise formula and an assumed power law increase in wind speed with height that depends on stability.

The material presented is directed toward the engineer familiar with computer techniques and will enable him to perform calculations with the CDM. Technical details of the computer programming are discussed; complete descriptions of input, output, and a test case are given. Flow diagrams and a source program listing are included. Companion papers by Calder (1971) on the technical details of the model and by Turner et al. (1972) on validation are included.

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USER'S GUIDE
FOR THE
CLIMATOLOGICAL DISPERSION MODEL

1. INTRODUCTION

This report describes the computer program for the Climatological Dispersion Model (CDM) and its use in estimating long-term concentrations of nonreactive pollutants due to emissions from area and point sources in an urban area. Two pollutants may be considered simultaneously, the most frequent application being for sulfur dioxide and particulate matter. The program is written in FORTRAN IV language (level G) for the IBM 360/370 computers.

This model differs from the Air Quality Display Model (AQDM) primarily in the way in which concentrations are determined from area sources and in the use in the CDM of Briggs' plume rise formula and an assumed power law increase in wind speed with height that depends on the stability.

The material presented is directed toward the engineer familiar with computer techniques and will enable him to perform calculations with the CDM. Technical details of the computer programming are discussed; complete descriptions of input, output, and a test case are given; and a test example, flow diagrams, FORTRAN statements, and companion papers are presented as appendixes.

The relevant formulas for average concentrations resulting from emissions from area and point sources are presented in Section 2. (For a complete account of the theory, Appendix D should be consulted.) Section 3 contains information on the grid system, the emission inventory, and meteorological parameters. In addition, the sequence of cards for input data is given. The most tedious part of the computations arose from the area source calculations. Thus, it was considered important that the algorithms used in the computational program for area sources be described in some detail. These are given in Section 4. Finally, Section 5 contains a discussion on the computational output that can be obtained by using the program.

A test example, flow diagrams, and FORTRAN statements are presented in Appendixes A, B, and C, respectively. Companion papers by Calder (1971) and Turner et. al. (1972) have been reprinted as Appendixes D and E.

2. CONCENTRATION FORMULAS

The average concentration $\overline{C}_A$ due to area sources at a particular receptor is given by

$$\overline{C}_A = \frac{16}{2\pi} \int_0^{\infty} \left[\sum_{k=1}^{16} q_k(\rho) \sum_{\ell=1}^{6} \sum_{m=1}^{6} \phi(k,\ell,m) S(\rho,z;U_\ell,P_m) \right] d\rho \qquad (1)$$

where

k = index identifying wind direction sector

$q_k(\rho) = \int Q(\rho,\theta)\, d\theta$ for the k sector

$Q(\rho,\theta)$ = emission rate of the area source per unit area and unit time

ρ = distance from the receptor to an infinitesimal area source

θ = angle relative to polar coordinates centered on the receptor

ℓ = index identifying the wind speed class

m = index identifying the class of the Pasquill stability category

$\phi(k,\ell,m)$ = joint frequency function

$S(\rho,z;U_\ell,P_m)$ = dispersion function defined in Equations 3 and 4

z = height of receptor above ground level

U_ℓ = representative wind speed

P_m = Pasquill stability category

For point sources, the average concentration $\overline{C}_p$ due to n point sources is given by

$$\overline{C}_p = \frac{16}{2\pi} \sum_{n=1}^{n} \sum_{\ell=1}^{6} \sum_{m=1}^{6} \frac{\phi(k_n,\ell,m) G_n S(\rho_n, z; U_\ell, P_m)}{\rho_n} \qquad (2)$$

where

k_n = wind sector appropriate to the n^{th} point source

G_n = emission rate of the n^{th} point source

ρ_n = distance from the receptor to the n^{th} point source

If the receptor is presumed to be at ground level, that is, $z = 0$, then the functional form of $S(\rho,z;U_\ell,P_m)$ will be

$$S(\rho,0;U_\ell,P_m) = \frac{2}{\sqrt{2\pi}\, U_\ell\, \sigma_z(\rho)} \exp\left[-\frac{1}{2}\left(\frac{h}{\sigma_z(\rho)}\right)^2\right] \exp\left(\frac{-0.692\rho}{U_\ell T_{\frac{1}{2}}}\right) \qquad (3)$$

if $\sigma_z(\rho) \leq 0.8$ L and

$$S(\rho,0;U_\ell,P_m) = \frac{1}{U_\ell L} \exp\left(\frac{-0.692\rho}{U_\ell T_{\frac{1}{2}}}\right) \qquad (4)$$

if $\sigma_z(\rho) > 0.8$ L. New terms in Equations 3 and 4 are defined as follows:

$\sigma_z(\rho)$ = vertical dispersion function, i.e., the standard deviation of the pollution concentration in the vertical plane

h = effective stack height of source distribution, i.e., the average height of area source emissions in the k^{th} wind direction sector at radial distance ρ from the receptor

L = the afternoon mixing height

$T_{\frac{1}{2}}$ = assumed half life of pollutant, hours

The possibility of pollutant removal by physical or chemical processes is included in the program by the decay expression $\exp(-0.692\rho/U_\ell T_{\frac{1}{2}})$.

The total concentration for the averaging period is the sum of concentrations of the point and area sources for that averaging period.

3. PREPARATION OF INPUT DATA

GRID SYSTEM AND AREA EMISSIONS

A rectangular grid array of uniform-sized squares is used to overlay the region of interest. The main purpose of this grid is to catalogue the emission inventories by area sources. There is some flexibility in the size of the grid squares in that the computer program will accept information on emissions from squares whose sides have lengths which are integer multiples of the length of the side of the basic square. Thus, if the basic square has a length s, emission information for a larger square whose side has a length, say 4s, will be accepted by the computer and be distributed uniformly into 16 basic squares in the correct manner.

The origin of the overlay grid is located in the lower left-hand corner of the array with the X-axis pointing toward the east and the Y-axis pointing toward the north. With respect to the map coordinates of the region, the origin of the grid array is to be located at some suitably chosen point in the lower left-hand section of the region under consideration. The length of a side of a square is expressed in meters. However, the map coordinates can be expressed in any suitable units, say, thousands of feet or kilometers. The magnitude of the length of a square will depend on how many squares are needed in the emission inventory of a region. The computer program is dimensioned to accept 2500 area sources and 200 point sources. Computations can be performed for any number of receptor points.

METEOROLOGICAL PARAMETERS

Joint Frequency Function

It is necessary to have information on the joint frequency function $\phi(k,\ell,m)$ as input for the model. This function gives the joint frequency of occurrence of a wind direction sector k, a wind speed class ℓ, and a stability category index m. There are 576 entries in the table for the joint frequency function. This number of values results from the 16 different wind vectors, 6 wind speed classes, and 6 stability classes used in determining the frequency function.

Weather observations are taken hourly by meteorologists of the National Weather Service at airports serving major urban areas. In most circumstances, these weather data will be representative of the meteorological conditions of adjacent urban areas. This weather information for localities throughout the United States can be obtained from the National Climatic Center (NCC) located in Asheville, North Carolina. The Day-Night version of the NCC program called STAR gives the proper form of the joint frequency function, which may be used directly as input into the Climatological Dispersion Model.

The stability classification of the Day-Night STAR program differs from the original STAR program in that the Pasquill-Gifford stability class 4 has been separated into two classes, 4 and 5, representing neutral (P-G stability class 4) daytime conditions and neutral (P-G stability class 4) nighttime conditions, respectively. In addition, in the revised program the remaining nighttime Pasquill-Gifford stability classes (5 and 6) are lumped into class 6. The relation between the Pasquill-Gifford stability classes and those used in the Climatological Dispersion Model is shown in Table 1.

Table 1. PASQUILL-GIFFORD AND CLIMATOLOGICAL DISPERSION MODEL STABILITY CLASSES

Pasquill-Gifford	P_m
1	1
2	2
3	3
4 daytime	4
4 nighttime	5
5 6	6

The wind speed U for the various weather bureau classes (Table 2) is taken as the central wind speed of the class. It should be noted that the central wind speed of the lowest wind speed class was arbitrarily taken as 1.5 meters per second. This means that light winds reported in the first wind speed class were rounded up to this value, since most operational wind instruments do not sense low wind speeds accurately. Operational wind instruments are designed for durability and also to withstand exposure to strong, gusty airflow. For these reasons, most wind sensors have a high starting speed, which can lead to the erroneous reporting of light winds as calms (Truppi, 1968).

Table 2. CENTRAL WIND SPEEDS

Wind speed class	Speed interval, knots	Class wind speed, m/sec
1	0 to 3	1.50
2	4 to 6	2.46
3	7 to 10	4.47
4	11 to 16	6.93
5	17 to 21	9.61
6	> 21	12.52

Wind Profile

To account for an increase of wind with height above a height of 10 meters (anemometer height) to the level of emission, a power law relation of the form

$$U(z) = U_g(z/z_0)^p \tag{5}$$

is used in the computational program. The exponent p, as determined by DeMarrais (1959), depends on the stability class and is given in Table 3.

Table 3. EXPONENTS FOR WIND PROFILE

Stability class	Exponent (p)
1	0.1
2	0.15
3	0.20
4	0.25
5	0.25
6	0.30

Mixing Height

The magnitude of the mixing height undergoes considerable diurnal, seasonal, and annual variation. It is impractical to account for all such variations in detail. Nevertheless, some recognition is given to changes in the magnitude of the mixing height by assigning values to different stabilities according to Table 4.

Table 4. MIXING HEIGHT

Stability class	Mixing height, meters
1	1.5 x HT
2	HT
3	HT
4 day	HT
4 night	(HT + HMIN)/2
5	HMIN
6	HMIN

In Table 4, HT is the climatological mean value of the mixing height as tabulated by Holzworth (1972) and HMIN is the nocturnal mixing height.

Stability Classes

The lower layer of the urban atmosphere is generally more unstable than is the corresponding adjacent rural atmosphere. To account for this, modifications have been made to the stability class applied in the calculation of concentration from area sources. This modification consists of decreasing the stability class by one class with the exception of P_1, which is unaltered. This correction is not applied to point sources.

During the night with a surface inversion condition and a rural class stability of P_5, the neutral stability class P_4 is assumed for both point and area sources. Otherwise, there is no modification of the stability classes applied to point source calculations.

Dispersion Functions

An analytical approximation to the curves of Pasquill (1961) and Gifford (1961) for the vertical dispersion function $\sigma_z(\rho)$ is made by using an empirical power law in the form

$$\sigma_z(\rho) = a\rho^b \tag{6}$$

The parameters a and b for various stabilities and ranges of distance ρ are given in Table 5.

Table 5. PARAMETRIC VALUES FOR $\sigma_z(\rho)$

	Distance, meters					
	100 to 500		500 to 5000		5000 to 50,000	
Stability class	a	b	a	b	a	b
1	0.0383	1.2812	0.2539×10^{-3}	2.0886	-	-
2	0.1393	0.9467	0.4936×10^{-1}	1.1137	-	-
3	0.1120	0.9100	0.1014	0.9260	0.1154	0.9109
4	0.0856	0.8650	0.2591	0.6869	0.7368	0.5642
5	0.0818	0.8155	0.2527	0.6341	1.2969	0.4421
6	0.0545	0.8124	0.2017	0.6020	1.5763	0.3606

An initial value of the dispersion function $\sigma_z(0)$ is used in the program to represent the vertical dispersion created by the roughness of urban topography (buildings). For area sources, it is possible to input a different value of initial σ_z for each stability class, that is, six different values. Normally, however, and as shown in the illustrative example, the same value (30 meters) is used for all stability classes.

The value of initial σ_z for point sources has been made a function of the height of the stack above the ground. For stacks at ground level to 20 meters above the ground level, initial σ_z is assumed to be 30 meters. For stack heights between 20 and 50 meters above the ground level, initial σ_z is decreased linearly according to the equation

$$\sigma_z(0) = 50 - H \qquad (7)$$

where H is the stack height in meters. For stacks 50 meters above the ground or higher, the value of initial σ_z is zero.

Plume Rise

There are provisions in the program for the user to have a choice in estimating the plume rise. The first option makes use of the "2/3 law" due to Briggs (1971). The formula is given by

$$\Delta h = 1.6\, F^{1/3}\, U^{-1} \rho^{2/3} \qquad \rho \leq 3.5X^* \qquad (8)$$

and

$$\Delta h = 1.6\, F^{1/3}\, U^{-1}\, (3.5X^*)^{2/3} \qquad \rho > 3.5X^* \qquad (9)$$

$$X^* = 14\, F^{5/8} \quad \text{if } F \leq 55$$

$$X^* = 34\, F^{2/5} \quad \text{if } F > 55.$$

where
Δh = plume rise, meters
$F = gV_s R_s^2 \left[(T_s - T_a)/T_s\right]$
g = acceleration due to gravity, m/sec^2
V_s = average exit velocity of gases of plume, m/sec
R_s = inner radius of stack, meters
T_s = average temperature of gases in plume, °K
T_a = ambient air temperature, °K
U = wind speed at stack height, m/sec
ρ = distance from source to receptor, meters

As suggested by Briggs, ρ/X^* was not allowed to exceed the limiting value of 3.5.

For the other option on plume rise, the value of the product of the average wind speed and the height of plume rise may be used. This option permits no variation of this product with distance from the stack and the magnitude of the plume rise is at the discretion of the user.

CALIBRATION OF THE COMPUTED CONCENTRATION

If calibration constants of the linear expression

$$C' = A + BC \qquad (10)$$

where
C' = calibrated concentration
A, B = calibration constants
C = computed concentration

are known, they may be entered into the program and used to obtain a calibrated concentration. The calibration constants are determined from regression analysis of observed pollution data and the computed concentrations produced by the model. Thus, at least one initial run of the model must be made without use of the calibration feature. Once the model has been run to obtain computed concentrations, a regression analysis may be made of computed and observed concentration data. After finding the calibration constants, calibrated concentrations can be obtained on subsequent operations of the model.

In order to have both measured and observed data on computer cards for input to a regression analysis, it is possible to enter the observed concentrations on the receptor input cards. This value will then be punched on the output cards containing the calculated pollution concentrations.

If it is not desired to use the calibration feature, the value of the calibration constants A and B should be specified as 0 and 1 respectively. This will result in the output of a "calibrated" concentration value identical to the computed value.

CARD INPUT SEQUENCE

The arrangement of input data on the cards that follow the program deck is given in Table 6. Certain data that are permanent features of the model, such as the wind speed of classes and wind direction of classes, are a part of the program and not read in as separate entities. Interactive operation, discussed in the next section, requires an input data set somewhat different from that given in Table 6.

Table 6. CARD INPUT SEQUENCE

Card No.	Column	Format	Contents
1	1 to 8	2A4	AROS(1)-AROS(2) (Identification for punched output of the computed area source concentrations of the two pollutants. See sample punched output.)
	9 to 16	2A4	PROS(1)-PROS(2) (Identification for punched output of the computed point source concentrations of the two pollutants)
	17 to 21	I5	IRUN (Computer run identification number)
	22 to 26	I5	NLIST (Index which indicates whether input data should belisted. If NLIST ≤ 0, input data is printed.)
	27 to 31	I5	IRD (Card input file number)
	32 to 36	I5	IWR (Output print file number)
	37 to 41	I5	IPU (Output punch file number)
	42 to 59	2F9.0	CA(1)-CA(2) (Constants of the linear equation Y= CA + CB x X, used to calibrate the calculated concentrations of the two pollutants considered in the model)

Table 6 (continued). CARD INPUT SEQUENCE

Card No.	Column	Format	Contents
	60 to 77	2F9.0	CB(1)-CB(2) (Slope of the linear equation, Y = CA + CB x X, used to calibrate the calculated concentrations of the two pollutants considered in the model)
2	1 to 6	F6.0	DELR (Initial integration increment of radial distance from receptor, meters)
	7 to 12	F6.0	RAT (Ratio of length of a basic emission grid square and the length of a map grid square)
	13 to 18	F6.0	CV (Conversion factor which upon multiplication by RAT expresses the distance of the side of an emission grid square in meters. For example, if the map units are in kilometers, CV=1000.)
	19 to 24	F6.0	HT (Average afternoon mixing height in meters)
	25 to 30	F6.0	HMIN (Average nocturnal mixing height in meters)
	31 to 36	F6.0	XG (X map coordinate of the southwest corner of the emission grid array)
	37 to 42	F6.0	YG (Y map coordinate of the southwest corner of the emission grid array)
	43 to 48	F6.0	XGG (X map coordinate of the southwest corner of the plotting grid)
	49 to 54	F6.0	YGG (Y map coordinate of the southwest corner of the plotting grid)
	55 to 60	F6.0	RATG (Ratio of the length of the grid square used for plotting and the length of a map grid square)
	61 to 66	F6.0	TOA (Mean atmospheric temperature in degrees centigrade)
	67 to 72	F6.0	TXX (Width of basic emission square in meters)
3	1 to 6	F6.0	DINT (Number of intervals used to integrate over a 22.5° sector. Maximum value is 20, typical value is 4.)
	7 to 12	F6.0	YD (Ratio of average daytime emission rate to the 24-hour emission rate average)

Table 6 (continued). CARD INPUT SEQUENCE

Card No.	Column	Format	Contents
	13 to 18	F6.0	YN (Ratio of the average nighttime emission rate to the 24-hour emission rate average)
	19 to 54	6F6.0	SZA(1)-SZA(6) (Initial σ_z in meters for each stability class. Six different values can be used, but normally only one value is used.)
	55 to 66	2F6.0	GB(1)-GB(2) (Decay half life in hours for the two pollutants)
4-99	1 to 63	[9X,6(1X, F8.6)]	F(i,j,k) (Joint frequency function, identical to $\phi(k,\ell,m)$; i = index for stability class, j = index for wind speed, k = index for wind direction. See input data of sample problem for proper ordering of this parameter by stability class, wind direction, and wind speed.)
[Source cards follow]			
100[a]	1 to 6	F6.0	X(X map coordinate of the southwest corner of the area emission grid, or if appropriate, the X map coordinate of a point source)
	7 to 13	F7.0	Y (Y map coordinate of the southwest corner of the area emission grid, or if appropriate, the Y map coordinate of a point source)
	14 to 20	F7.0	TX (Width of an area grid square in meters. It is important that no entry be made in the case of a point source.)
	21 to 36	2F8.0	S1-S2 (Source emission rate in grams per second for the two pollutants)
	37 to 43	F7.0	SH (Stack height in meters)
	44 to 49[b]	F5.0	D (Diameter of stack in meters)
	50 to 56[b]	F7.0	VS (Exit speed of pollutants from stack in meters per second)
	57 to 63[b]	F7.0	T (Gas temperature of stack gases in degrees centigrade)
	64 to 68[b]	F5.0	SA (If this field is blank, Briggs' formula is used to compute stack height. Otherwise, the product of plume rise and wind speed is entered in square meters per second.)

Table 6 (continued). CARD INPUT SEQUENCE

Card No.	Column	Format	Contents
1000	--	--	This is a blank card which follows information on the emission sources. It is used to test the end of sources and must not be left out.
[Receptor cards follow]			
1001[c]	1 to 8	F8.2	RX (X map coordinate of the receptor)
	9 to 16	F8.2	RY (Y map coordinate of the receptor)
	31 to 34	I4	KPX(9) (Observed concentration at the receptor of the first pollutant)
	38 to 41	I4	KPX(10) (Observed concentration at the receptor of the second pollutant)
	42 to 46	I5	NROSE (A control that, if greater than zero, will print out histogram concentration data. If left blank, no histogram data will be printed.)

[a] There will be as many cards of this type as there are area and point sources. The next card type will arbitrarily be numbered 1000.

[b] Needed for point sources only. Leave blank on area source cards.

[c] There will be as many cards of this type as there are receptors.

Listing of card input for the test case (Table A.1) should be helpful. However, several parameters may need additional explanation.

The parameter DELR has usually been set at 250 meters. Assume that an emission inventory exists with the smallest emission square 5000 feet on a side. Also assume that all coordinates are given in feet. In this case the basic emission grid square would be 5000 feet on a side and RAT would be 5000, CV would be 0.3048, TXX would be 1524, and XG, YG, XGG, and YGG would all be in feet. Also, all source and receptor coordinates would be expressed in feet (map coordinates).

Now assume that it is desirable to plot the resulting concentrations on a grid system with 1-kilometer spacing. The lower left corner of this grid is specified by the map coordinates (in feet) as XGG,YGG; and RATG would be 1.524. In this example, TX on the source cards would be 1524 or some multiple of this number for the area sources.

INTERACTIVE OPERATION

The Climatological Dispersion Model is now accessible to qualified users on remote computer terminals by means of telephone hookup to the Environmental Protection Agency computer facilities in the Research Triangle Park, North Carolina. The interactive version of the model requires an input data set that is almost the same as has been described in the previous section. For interactive processing of the model, a catalogued data set, whose name is passed on to the model as a parameter, must be created under standard TSO or TSO/BATCH procedures.

An example TSO data set, which has been given the name TESTSET, is listed in Tables 7 and 8. This interactive input data set is different from that described in the previous section in two respects. The first is that there are fewer parameters required on the first three input cards and the second is that receptor locations are submitted interactively from the computer terminal. Data for the first three cards are entered consecutively, starting in column one for each card and separating the items by commas, as illustrated in Table 7.

Table 7. DATA LISTED ON FIRST THREE CARDS OF AN INTERACTIVE DATA SET

Card	List	Example
1	IRUN, IRD, IWR, CA, CE	Col 1 99999,5,6,0,0,1,1
2	DELR, RAT, CV, HT, HMIN, XG, YG, TOA, TXX	250,5,1000,800,150,5,5, 1.25,5000
3	DINT, YD, YN, SZA, GB	4,1,1,30,30,30,30,30,30 3,999999

The self-explanatory listing in Table 9 illustrates the operation of the Climatological Dispersion Model with an interactive computer terminal. The user submits computer commands in lower-case letters, and the computer responds in upper-case letters.

Table 8. LISTING OF THE EXAMPLE TSO DATA SET, TESTSET

```
list testset.data
 TESTSET.DATA
00010 99999,5,6,0.,0.,1.,1.
00020 250.,5.,1000.,800.,150.,5.,5.,1.25,5000.
00030 4.,1.,1.,30.,30.,30.,30.,30.,30.,3.,999999.
00040
00050
    ↑

    44 blank cards

    ↓
00500
00510
00520                 0.0625
00530                 0.0625
00540                 0.0625
00550                 0.0625
00560                 0.0625
00570                 0.0625
00580                 0.0625
00590                 0.0625
00600                 0.0625
00610                 0.0625
00620                 0.0625
00630                 0.0625
00640                 0.0625
00650                 0.0625
00660                 0.0625
00670                 0.0625
00680
00690
00700
    ↑

    24 blank cards

    ↓
00950
00960
00970
00980
00990
01000    5.0     5.0 10000.   4000.0   4000.0 20.0
01010    5.0    15.0  5000.   1000.0   1000.0 20.0
01020   10.0    15.0  5000.   1000.0   1000.0 20.0
01030   15.0    15.0  5000.   1000.0   1000.0 20.0
01040   15.0    10.0  5000.   1000.0   1000.0 20.0
01050   15.0     5.0  5000.   1000.0   1000.0 20.0
01060   12.5    12.5     0.   1000.0   1000.0 20.0  20.0 5.0 1.0  0.0
READY
```

Table 9. INTERACTIVE OPERATION OF CLIMATOLOGICAL DISPERSION MODEL, TESTSET LISTING

```
"logan user id p (unamap) non
XXXXX LOGON IN PROGRESS AT 10:31:55 ON FEBRUARY 13, 1973
NO BROADCAST MESSAGES
LOGON PROCEEDING
READY
cdm testset
UTILITY DATA SET NOT FREED, IS NOT ALLOCATED
DO YOU WANT A PARTIAL LISTING OF MODEL PARAMETERS?  ENTER YES OR NO.
yes
                                     CDMI VERSION 73043,  RUN 99999
THE CENTRAL WIND SPEEDS OF THE SIX WIND SPEED CLASSES (U):
      0.150000E+01      0.245872E+01      0.447040E+01      0.692912E+01      0.961136E+01      0.125171E+02
THE EXPONENTIAL OF THE VERTICAL WIND PROFILE BY STABILITY CLASS (UE):
      0.100000E+00      0.150000E+00      0.200000E+00      0.250000E+00      0.250000E+00      0.300000E+00
THE INITIAL SIGMA Z FOR AREA SOURCES BY STABILITY CLASS (SZA):
      0.300000E+02      0.300000E+02      0.300000E+02      0.300000E+02      0.300000E+02      0.300000E+02
THE CLIMATOLOGICAL MEAN NOCTURNAL AND AFTERNOON MIXING HEIGHTS (HMIN,HT):
      0.150000E+03      0.800000E+03
THE DAY AND NIGHT EMISSION WEIGHT FACTORS (YD,YN):
      0.100000E+01      0.100000E+01
THE X-MIN AND Y-MIN OF THE AREA EMISSION INVENTORY GRID (XG,YG):
      0.750000E+01      0.750000E+01
THE WIDTH OF A BASIC AREA SOURCE SQUARE (TXX):
      0.500000E+04
THE NUMBER OF SUB-SECTORS CONSIDERED IN A 22.5 DEGREE SECTOR, AND ANGULAR WIDTH OF A SUB-SECTOR (DINI,THETA):
      0.400000E+01      0.562500E+01
THE INITIAL RADIAL INCREMENT (DELR):
      0.250000E+03
THE RADIAL INCREMENT FACTORS (INC):
                 1                 2                 4                 4
THE RATIO OF EMISSION GRID TO MAP GRID (RAT):
      0.500000E+01
THE GRID CONVERSION FACTOR (CV):
      0.100000E+04
THE AMBIENT AIR TEMPERATURE (TOA):
      0.274410E+03
THE DECAY RATE HALF LIFE FOR P 1 AND P 2 (GB):
      0.300000E+01      0.999999E+06
       6 AREA SOURCE(S).        1 POINT SOURCE(S).
WHEN  ?  APPEARS, ENTER RECEPTOR COORDINATES (X,Y) OR ENTER  /*  TO TERMINATE.

?
12.5,12.5
```

Table 9 (continued). INTERACTIVE OPERATION OF CLIMATOLOGICAL DISPERSION MODEL, TESTSET LISTING

```
                                 CDMI VERSION 73043,  RUN 99999
                                  (MICROGRAMS PER CUBIC METER)
                        AREA                 POINT                TOTAL            CALIBRATED
   COORDINATES       P 1      P 2         P 1      P 2         P 1      P 2         P J      P 2
  12.50    12.50     810.     886.         0.       0.         810.     886.        810      886.
AREA  ROSES
P 1      49  50  53  50  49  50  53  50  49  50  53  50  49  50  53  50
P 2      53  55  58  55  53  55  58  55  53  55  58  55  53  55  58  55
POINT ROSES
P 1       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
P 2       0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
?
5,5
   5.00     5.00     304.     349.        31.      45.         334.     394.        334.     394.
AREA  ROSES
P 1      39  61  64  61  39   4   4   4   4   4   4   4   4   4   4   4
P 2      45  71  76  71  45   4   4   4   4   4   4   4   4   4   4   4
POINT ROSES
P 1       0   0  31   0   0   0   0   0   0   0   0   0   0   0   0   0
P 2       0   0  45   0   0   0   0   0   0   0   0   0   0   0   0   0
?
20,20
  20.00    20.00     304.     349.        31.      45.         334.     394.        334.     394.
AREA  ROSES
P 1       4   4   4   4   4   4   4   4  39  61  64  61  39   4   4   4
P 2       4   4   4   4   4   4   4   4  45  71  76  71  45   4   4   4
POINT ROSES
P 1       0   0   0   0   0   0   0   0   0   0  31   0   0   0   0   0
P 2       0   0   0   0   0   0   0   0   0   0  45   0   0   0   0   0
?
-5,12.5
  -5.00    12.50      32.      59.        11.      21.          44.      81.         44.      81.
AREA  ROSES
P 1       0   0   0   9  14   9   0   0   0   0   0   0   0   0   0   0
P 2       0   0   0  16  27  16   0   0   0   0   0   0   0   0   0   0
POINT ROSES
P 1       0   0   0   0  11   0   0   0   0   0   0   0   0   0   0   0
P 2       0   0   0   0  21   0   0   0   0   0   0   0   0   0   0   0
?
/*
UTILITY DATA SET NOT FREED, IS NOT ALLOCATED
READY
logoff
XXXXX LOGGED OFF TSO AT 10:45:03 ON FEBRUARY 13, 1973+
```

4. ALGORITHMS FOR CONTRIBUTIONS BY AREA SOURCES

Although in principle there is no difficulty in computing the contribution to the average concentration by the multitude of area sources, it is rather tedious. Since various computational procedures can be used to determine these contributions, it is relevant to detail the procedures used in this program.

Let us suppose that the receptor, R, is located within the grid array as shown in Figure 1. The first step in the program is to determine the distance from the receptor to the furthest corner of the grid array. This distance is taken as the upper limit ρ_M of the integral $q_k(\rho)$ in Equation 1. Figure 1 also shows one of the sectors for which integrations are to be carried out.

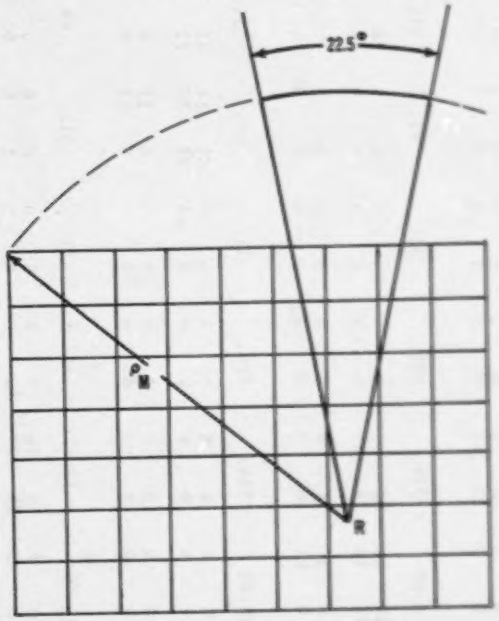

Figure 1. Illustration of sector integration.

An angular integration using the trapezoidal rule is carried out numerically. This integration determines $q_k(\rho)$ at various increments of ρ, as indicated in Table 10. The integration to determine concentration (Equation 1) is accomplished next using the trapezoidal rule. As shown in Figure 1, the integration over ρ extends beyond the boundary of the grid system. No additional contribution to the concentration will occur, however, because the source density is zero beyond the grid boundary.

Table 10. INCREMENTS OF INTEGRATION

Range, meters	Increment, meters
$0 \leq \rho \leq 2500$	250[a]
$2500 \leq \rho \leq 5000$	500
$5000 \leq \rho \leq \rho_M$	1000

[a] The user can specify any value that is felt to be appropriate by specifying the value for DELR in the input. If a value different than 250 is specified for DELR, the increments in the table would change proportionately.

The program is also designed to handle the case where the receptor lies outside of the emission grid array. For this case, the nearest distance ρ_m to the grid boundary as well as the maximum distance ρ_M is found. The lower limit to the integral in Equation 1 is ρ_m and the upper limit is ρ_M. Evaluating the integral in Equation 1 from a lower limit, ρ_m, instead of from zero results in a savings in computer time.

5. COMPUTATIONAL OUTPUT (BATCH MODE)

In Appendix A, output is displayed for the test example. Table A-2 contains information on input data, which may prove useful to the interpretation of the calculated concentrations. Printing of these input data (which will be voluminous if there are many sources) can be suppressed by punching a positive number for the variable NLIST (first input card).

Table A-3 displays the calculated contribution due to area and point sources in micrograms per cubic meter to the nearest whole number. As discussed in Section 3, "calibrated" concentration values are also printed out. To employ the calibration feature, however, it is necessary to have made a preliminary regression analysis and to have inserted the proper parameters in the first card of the input sequence. Thus, for the test example, "calibrated" values are identical to computed values.

An unfolding of the computed concentrations according to sectors of the wind direction can also be given at each receptor point if desired. This is controlled by the input variable NROSE. The concentrations are displayed clockwise in the sequence, N, NNE, . . . , NNW.

The calculated concentration is also punched on cards so that an isopleth plot of the concentrations may be obtained, if desired. At the option of the user, the output of the contributions to the concentrations by each wind sector may also be punched on cards and used to make a histogram plot.

REFERENCES

Briggs, G.A., 1971. Some Recent Analyses of Plume Rise Observation. In: Proceedings of the Second International Clean Air Congress, Englund, H.M. and W.T. Baery (ed.). New York, Academic Press, 1971.

Calder, K.L., 1971. A Climatological Model for Multiple Source Urban Air Pollution. In: Proceedings of the Second Meeting of the Expert Panel on Air Pollution Modeling. NATO, Committee on the Challenges of Modern Society (CCMS). Paris, France. July 26-27, 1971.

DeMarrais, G.A., 1959. Wind Speed Profiles at Brookhaven National Laboratory. J. Appl. Meteorol. 16: 181-189, 1959.

Gifford, F.A., 1961. Uses of Routine Meteorological Observation for Estimating Atmospheric Dispersion. Nuclear Safety. 2 (4): 47-51, 1961.

Holzworth, G.C., 1972. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution throughout the Contiguous United States. Office of Air Programs, Environmental Protection Agency, Research Triangle Park, N.C. Publication No. AP-101. January 1972.

McElroy, J.L. and F. Pooler, Jr., 1968. St. Louis Dispersion Studies; Vol. II - Analysis. National Air Pollution Control Administration. Arlington, Va. Publication No. AP-53. December 1968.

Pasquill, F., 1961. The Estimation of the Dispersion of Windborne Material. Meteorol. Magazine. 90 (1063): 33-49, 1961.

Truppi, L.E., 1968. Bias Introduced by Anemometer Starting Speeds in Climatological Wind Rose Summaries. Monthly Weather Review. 96 (5): 325-327, May 1968.

Turner, D.B., J.R. Zimmerman, and A.D. Busse, 1972. An Evaluation of Some Climatological Dispersion Models. In: Proceedings of the Third Meeting of the Expert Panel on Air Pollution Modeling. NATO, Committee on the Challenges of Modern Society (CCMS). Paris, France. October 2-4, 1972.

GLOSSARY

A, B = calibration constants

$\overline{C}_A$ = average concentration due to area sources, $\mu g/m^3$

$\overline{C}_P$ = average concentration due to point sources, $\mu g/m^3$

$F = gV_sR_s^{\,2}\,[(T_s - T_a)/T_s]$

g = acceleration due to gravity, m/sec^2

G_n = emission rate of n^{th} point source

h = effective stack height, meters

H = stack height, meters

HMIN = nocturnal mixing height, meters

HT = climatological mean value of mixing height, meters

k = index identifying wind direction sector

k_n = wind sector appropriate to n^{th} point source

ℓ = index identifying wind speed class

L = afternoon mixing height

m = index identifying class of Pasquill stability category

n = number of point sources

p = wind profile exponent

P_m = stability class

$Q(\rho,\theta)$ = emission rate of an area source per unit area and unit time

$q_k(\rho) = \int Q(\rho,\theta)\,d\theta$

R_s = inner radius of stack, meters

$S(\rho,z;U_\ell,P_m)$ = dispersion function

$T_{\frac{1}{2}}$ = pollutant half life, hours

T_a = ambient air temperature, °K

T_s = average temperature of gases in plume, °K

U = wind speed at stack height, m/sec

U_ℓ = representative wind speed, m/sec

V_s = average exit velocity of gases of plume, m/sec

X, Y = axes of the grid system; the X axis points east, the Y axis north

z = height of receptor above ground level, meters

Δh = plume rise, meters

θ = angle relative to polar coordinates centered on receptor

ρ = distance from receptor to source, meters

ρ_n = distance from receptor to n^{th} point source, meters

$\sigma_z = \sigma_z(\rho)$ = dispersion function, i.e., standard deviation of pollution concentration in vertical plane

$\phi(k,\ell,m)$ = joint frequency function

APPENDIX A. TEST EXAMPLE

INTRODUCTION

To illustrate various features described earlier and to provide a test that the program is operating properly, a hypothetical problem has been constructed for the convenience of the user. It is supposed that a source inventory of an area has been made. The source inventory grid is depicted in Figure A-1.

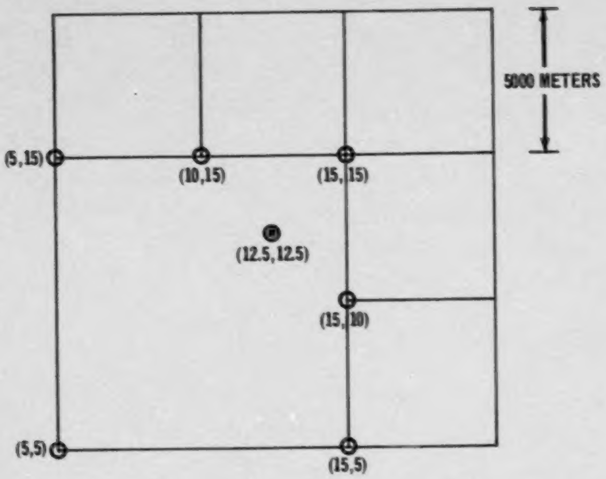

Figure A.1. Emission grid for test problem.

The southwest corner of each grid square is shown and its location given in kilometers in map coordinate units. The length of the side of a basic square is 5000 meters. It should be noted that length of the side of the larger square is larger than that of the basic square by an integral multiple. The program will automatically divide this large square into four basic squares and assign the correct emission rates. It is assumed that each basic square emits pollutant at the rate of 1000 grams per second. The larger square emits pollutant at the rate of 4000 grams per second. The emission height of all the area sources is 20 meters. The circle on the sketch located at (12.5, 12.5) represents a point source. It is assumed to be emitting pollutant at the rate of 1000 grams per second from a stack which is 20 meters high.

CARD INPUT

Card input for the test example is listed in Table A-1.

PRINTED OUTPUT

Printed output for the test example is given in Tables A-2 and A-3. Table A-2 is a list of the input parameters used. A list of this type can be obtained if desired, or suppressed by entering a positive number for the variable NLIST on the first input card.

CARD OUTPUT

Cards containing the calculated concentrations at each receptor will be punched for use in computer programs that analyze the information produced by the Climatological Dispersion Model. As discussed in Section 3, a regression program must be applied to obtain calibration constants. Additionally, the punched output can be used to obtain isopleth plots of concentration contours, i.e., CALCOMP General Purpose Contouring Programs.

Besides the cards containing the total concentration from area and point sources, additional punched output may be produced if the NROSE option is used. If NROSE is specified as greater than zero, four additional cards will be punched; one card each for area and point source contributions to the concentration (a value is given for each wind sector) for the two pollutants. The format of the punched output is given in Table A-4, and Table A-5 is a listing of punched output for the sample problem. These punched cards are not output with the interactive version of the model.

ISOPLETHS AND HISTOGRAMS

The plotted isopleth and histograms (Figures A-2 and A-3) in this section were produced from the punched output of the test example. Unique plotting programs must be applied for different computer systems. Thus plotting programs have been omitted from this paper, and must be supplied by the user to obtain a comparable plotted output display.

Table A-1. CARD INPUT FOR THE TEST EXAMPLE

```
A P1A P2P P1P P299999   -1     5     6     7      0.0       0.0      1.0      1.0   00000010
 250.    5. 1000.  800.  150.   5.0   5.0   7.5   7.5    5.  1.25 5000.             00000020
   4.    1.    1.   30.   30.   30.   30.   30.   30.  3.0999999                    00000030

48 BLANK CARDS
              COL 10-18      COL 73-80          |        COL 10-18      COL 73-80
               0.0625        00000510           |         0.0625        00000590
               0.0625        00000520           |         0.0625        00000600
               0.0625        00000530           |         0.0625        00000610
               0.0625        00000540           |         0.0625        00000620
               0.0625        00000550           |         0.0625        00000630
               0.0625        00000560           |         0.0625        00000640
               0.0625        00000570           |         0.0625        00000650
               0.0625        00000580           |         0.0625        00000660
                                                |                       00000670

32 BLANK CARDS                                                                  00001000
  5.0     5.0 10000.  4000.0  4000.0   20.0                                     00001010
  5.0    15.0  5000.  1000.0  1000.0   20.0                                     00001020
 10.0    15.0  5000.  1000.0  1000.0   20.0                                     00001030
 15.0    15.0  5000.  1000.0  1000.0   20.0                                     00001040
 15.0    10.0  5000.  1000.0  1000.0   20.0                                     00001050
 15.0     5.0  5000.  1000.0  1000.0   20.0                                     00001060
 12.5    12.5     0.  1000.0  1000.0   20.0   1.0    5.0   20.0   0.0           00001070

    COL 1-8  COL 9-16    COL 46   COL 73-80    |  COL 1-8  COL 9-16    COL 46   COL 73-80
      5.0      5.0         1      00001080     |    5.0     18.75        1      00001190
      5.0      6.25               00001090     |    5.0     20.0                00001200
      5.0      7.5                00001100     |    6.25     5.0                00001210
      5.0      8.75               00001110     |    6.25     6.25               00001220
      5.0     10.0                00001120     |    6.25     7.5                00001230
      5.0     11.25               00001130     |    6.25     8.75               00001240
      5.0     12.5                00001140     |    6.25    10.0                00001250
      5.0     13.75               00001150     |    6.25    11.25               00001260
      5.0     15.0                00001160     |    6.25    12.5                00001270
      5.0     16.25               00001170     |    6.25    13.75               00001280
      5.0     17.5                00001180     |    6.25    15.0                00001290
```

Table A-1 (continued). CARD INPUT FOR THE TEST EXAMPLE

COL 1-8	COL 9-16	COL 46	COL 73-80	COL 1-8	COL 9-16	COL 46	COL 73-80
6.25	16.25		00001300	10.0	15.0		00001680
6.25	17.5		00001310	10.0	16.25		00001690
6.25	18.75		00001320	10.0	17.5		00001700
6.25	20.0		00001330	10.0	18.75		00001710
7.5	5.0		00001340	10.0	20.0		00001720
7.5	6.25		00001350	11.25	5.0		00001730
7.5	7.5		00001360	11.25	6.25		00001740
7.5	8.75		00001370	11.25	7.5		00001750
7.5	10.0		00001380	11.25	8.75		00001760
7.5	11.25		00001390	11.25	10.0		00001770
7.5	12.5		00001400	11.25	11.25		00001780
7.5	13.75		00001410	11.25	12.5		00001790
7.5	15.0		00001420	11.25	13.75		00001800
7.5	16.25		00001430	11.25	15.0		00001810
7.5	17.5		00001440	11.25	16.25		00001820
7.5	18.75		00001450	11.25	17.5		00001830
7.5	20.0		00001460	11.25	18.75		00001840
8.75	5.0		00001470	11.25	20.0		00001850
8.75	6.25		00001480	12.5	5.0		00001860
8.75	7.5		00001490	12.5	6.25		00001870
8.75	8.75		00001500	12.5	7.5		00001880
8.75	10.0		00001510	12.5	8.75		00001890
8.75	11.25		00001520	12.5	10.0		00001900
8.75	12.5		00001530	12.5	11.25		00001910
8.75	13.75		00001540	12.5	12.5		00001920
8.75	15.0		00001550	12.5	13.75		00001930
8.75	16.25		00001560	12.5	15.0		00001940
8.75	17.5		00001570	12.5	16.25		00001950
8.75	18.75		00001580	12.5	17.5		00001960
8.75	20.0		00001590	12.5	18.75		00001970
10.0	5.0		00001600	12.5	20.0		00001980
10.0	6.25		00001610	13.75	5.0		00001990
10.0	7.5		00001620	13.75	6.25		00002000
10.0	8.75		00001630	13.75	7.5		00002010
10.0	10.0		00001640	13.75	8.75		00002020
10.0	11.25		00001650	13.75	10.0		00002030
10.0	12.5		00001660	13.75	11.25		00002040
10.0	13.75		00001670	13.75	12.5		00002050

Table A-1 (continued). CARD INPUT FOR THE TEST EXAMPLE

COL 1-8	COL 9-16	COL 46	COL 73-80
13.75	13.75		00002060
13.75	15.0		00002070
13.75	16.25		00002080
13.75	17.5		00002090
13.75	18.75		00002100
13.75	20.0		00002110
15.0	5.0		00002120
15.0	6.25		00002130
15.0	7.5		00002140
15.0	8.75		00002150
15.0	10.0		00002160
15.0	11.25		00002170
15.0	12.5		00002180
15.0	13.75		00002190
15.0	15.0		00002200
15.0	16.25		00002210
15.0	17.5		00002220
15.0	18.75		00002230
15.0	20.0		00002240
16.25	5.0		00002250
16.25	6.25		00002260
16.25	7.5		00002270
16.25	8.75		00002280
16.25	10.0		00002290
16.25	11.25		00002300
16.25	12.5		00002310
16.25	13.75		00002320
16.25	15.0		00002330
16.25	16.25		00002340
16.25	17.5		00002350
16.25	18.75		00002360
16.25	20.0		00002370
17.5	5.0		00002380
17.5	6.25		00002390
17.5	7.5		00002400
17.5	8.75		00002410
17.5	10.0		00002420
17.5	11.25		00002430
17.5	12.5		00002440
17.5	13.75		00002450
17.5	15.0		00002460
17.5	16.25		00002470
17.5	17.5		00002480
17.5	18.75		00002490
17.5	20.0		00002500
18.75	5.0		00002510
18.75	6.25		00002520
18.75	7.5		00002530
18.75	8.75		00002540
18.75	10.0		00002550
18.75	11.25		00002560
18.75	12.5		00002570
18.75	13.75		00002580
18.75	15.0		00002590
18.75	16.25		00002600
18.75	17.5		00002610
18.75	18.75		00002620
18.75	20.0		00002630
20.0	5.0	1	00002640
20.0	6.25		00002650
20.0	7.5		00002660
20.0	8.75		00002670
20.0	10.0		00002680
20.0	11.25		00002690
20.0	12.5		00002700
20.0	13.75		00002710
20.0	15.0		00002720
20.0	16.25		00002730
20.0	17.5		00002740
20.0	18.75		00002750
20.0	20.0	1	00002760

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Table A-2. OUTPUT FOR TEST EXAMPLE, INPUT PARAMETERS USED

```
                              CDM VERSION 72313.  RUN 99999
THE CENTRAL WIND SPEEDS OF THE SIX WIND SPEED CLASSES (U):
     0.150000E 01       0.245872E 01       0.447040E 01       0.692912E 01       0.961136E 01       0.125171E 02
THE EXPONENTIAL OF THE VERTICAL WIND PROFILE BY STABILITY CLASS (UE):
     0.100000E 00       0.150000E 00       0.200000E 00       0.250000E 00       0.250000E 00       0.300000E 00
THE INITIAL SIGMA Z FOR AREA SOURCES BY STABILITY CLASS (SZA):
     0.300000E 02       0.300000E 02       0.300000E 02       0.300000E 02       0.300000E 02       0.300000E 02
THE CLIMATOLOGICAL MEAN NOCTURNAL AND AFTERNOON MIXING HEIGHTS (HMIN,HT):
     0.150000E 03       0.800000E 03
THE DAY AND NIGHT EMISSION WEIGHT FACTORS (YD,YN):
     0.100000E 01       0.100000E 01
THE X-MIN AND Y-MIN OF THE AREA EMISSION INVENTORY GRID (XG,YG):
     0.750000E 01       0.750000E 01
THE WIDTH OF A BASIC AREA SOURCE SQUARE (TXX):
     0.500000E 04
THE NUMBER OF SUB-SECTORS CONSIDERED IN A 22.5 DEGREE SECTOR, AND ANGULAR WIDTH OF A SUB-SECTOR (DINT,THETA):
     0.400000E 01       0.562500E 01
THE INITIAL RADIAL INCREMENT (DELR):
     0.250000E 03
THE RADIAL INCREMENT FACTORS (INC):
               1                  2                  4                  4
THE RATIO OF EMISSION GRID TO MAP GRID (RAT):
     0.500000E 01
THE GRID CONVERSION FACTOR (CV):
     0.100000E 04
THE AMBIENT AIR TEMPERATURE (TOA):
     0.274410E 03
THE DECAY RATE HALF LIFE FOR P 1 AND P 2 (GH):
     0.300000E 01       0.499999E 04
```

Table A-2 (continued). OUTPUT FOR TEST EXAMPLE, INPUT PARAMETERS USED

```
THE SIGMA Z COEFFICIENT TABLE (G):
       0.253900E-03       0.253900E-03       0.383000E-01        0.208860E 01        0.208860E 01        0.124170E 01
       0.493600E-01       0.493600E-01       0.139300E 00        0.111370E 01        0.111370E 01        0.946700E 00
       0.115400E 00       0.101400E 00       0.112000E 00        0.910900E 00        0.926000E 00        0.910000E 00
       0.736800E 00       0.259100E 00       0.856000E-01        0.564200E 00        0.686900E 00        0.865000E 00
       0.129690E 01       0.252700E 00       0.818000E-01        0.442100E 00        0.634100E 00        0.815500E 00

                                     COM VERSION 72313.  RUN 99999
              U1                 U2                 U3                  U4                  U5                  U6
SECTOR

                                     THE JOINT FREQUENCY FUNCTION FOR STABILITY CLASS  1

  1       0.0                0.0                0.0                 0.0                 0.0                 0.0
  2       0.0                0.0                0.0                 0.0                 0.0                 0.0
  3       0.0                0.0                0.0                 0.0                 0.0                 0.0
  4       0.0                0.0                0.0                 0.0                 0.0                 0.0
  5       0.0                0.0                0.0                 0.0                 0.0                 0.0
  6       0.0                0.0                0.0                 0.0                 0.0                 0.0
  7       0.0                0.0                0.0                 0.0                 0.0                 0.0
  8       0.0                0.0                0.0                 0.0                 0.0                 0.0
  9       0.0                0.0                0.0                 0.0                 0.0                 0.0
 10       0.0                0.0                0.0                 0.0                 0.0                 0.0
 11       0.0                0.0                0.0                 0.0                 0.0                 0.0
 12       0.0                0.0                0.0                 0.0                 0.0                 0.0
 13       0.0                0.0                0.0                 0.0                 0.0                 0.0
 14       0.0                0.0                0.0                 0.0                 0.0                 0.0
 15       0.0                0.0                0.0                 0.0                 0.0                 0.0
 16       0.0                0.0                0.0                 0.0                 0.0                 0.0

                                     THE JOINT FREQUENCY FUNCTION FOR STABILITY CLASS  2

  1       0.0                0.0                0.0                 0.0                 0.0                 0.0
  2       0.0                0.0                0.0                 0.0                 0.0                 0.0
  3       0.0                0.0                0.0                 0.0                 0.0                 0.0
  4       0.0                0.0                0.0                 0.0                 0.0                 0.0
  5       0.0                0.0                0.0                 0.0                 0.0                 0.0
  6       0.0                0.0                0.0                 0.0                 0.0                 0.0
  7       0.0                0.0                0.0                 0.0                 0.0                 0.0
  8       0.0                0.0                0.0                 0.0                 0.0                 0.0
  9       0.0                0.0                0.0                 0.0                 0.0                 0.0
 10       0.0                0.0                0.0                 0.0                 0.0                 0.0
 11       0.0                0.0                0.0                 0.0                 0.0                 0.0
 12       0.0                0.0                0.0                 0.0                 0.0                 0.0
 13       0.0                0.0                0.0                 0.0                 0.0                 0.0
```

Table A-2 (continued). OUTPUT FOR TEST EXAMPLE, INPUT PARAMETERS USED

```
                                CDM VERSION 72313.  RUN 99999
              U1               U2              U3             U4             U5             U6
SECTOR
  14     0.0               0.0             0.0            0.0            0.0            0.0
  15     0.0               0.0             0.0            0.0            0.0            0.0
  16     0.0               0.0             0.0            0.0            0.0            0.0

                                THE JOINT FREQUENCY FUNCTION FOR STABILITY CLASS  3

   1     0.0               0.0             0.0            0.0            0.0            0.0
   2     0.0               0.0             0.0            0.0            0.0            0.0
   3     0.0               0.0             0.0            0.0            0.0            0.0
   4     0.0               0.0             0.0            0.0            0.0            0.0
   5     0.0               0.0             0.0            0.0            0.0            0.0
   6     0.0               0.0             0.0            0.0            0.0            0.0
   7     0.0               0.0             0.0            0.0            0.0            0.0
   8     0.0               0.0             0.0            0.0            0.0            0.0
   9     0.0               0.0             0.0            0.0            0.0            0.0
  10     0.0               0.0             0.0            0.0            0.0            0.0
  11     0.0               0.0             0.0            0.0            0.0            0.0
  12     0.0               0.0             0.0            0.0            0.0            0.0
  13     0.0               0.0             0.0            0.0            0.0            0.0
  14     0.0               0.0             0.0            0.0            0.0            0.0
  15     0.0               0.0             0.0            0.0            0.0            0.0
  16     0.0               0.0             0.0            0.0            0.0            0.0

                                THE JOINT FREQUENCY FUNCTION FOR STABILITY CLASS  4

   1     0.625000E-01      0.0             0.0            0.0            0.0            0.0
   2     0.625000E-01      0.0             0.0            0.0            0.0            0.0
   3     0.625000E-01      0.0             0.0            0.0            0.0            0.0
   4     0.625000E-01      0.0             0.0            0.0            0.0            0.0
   5     0.625000E-01      0.0             0.0            0.0            0.0            0.0
   6     0.625000E-01      0.0             0.0            0.0            0.0            0.0
   7     0.625000E-01      0.0             0.0            0.0            0.0            0.0
   8     0.625000E-01      0.0             0.0            0.0            0.0            0.0
   9     0.625000E-01      0.0             0.0            0.0            0.0            0.0
  10     0.625000E-01      0.0             0.0            0.0            0.0            0.0
  11     0.625000E-01      0.0             0.0            0.0            0.0            0.0
  12     0.625000E-01      0.0             0.0            0.0            0.0            0.0
  13     0.625000E-01      0.0             0.0            0.0            0.0            0.0
  14     0.625000E-01      0.0             0.0            0.0            0.0            0.0
  15     0.625000E-01      0.0             0.0            0.0            0.0            0.0
  16     0.625000E-01      0.0             0.0            0.0            0.0            0.0
```

Table A-2 (continued). OUTPUT FOR TEST EXAMPLE, INPUT PARAMETERS USED

```
                                 CDM VERSION 72313,  RUN 99999
            U1          U2           U3           U4           U5           U6
SECTOR

                            THE JOINT FREQUENCY FUNCTION FOR STABILITY CLASS  5

  1        0.0         0.0          0.0          0.0          0.0          0.0
  2        0.0         0.0          0.0          0.0          0.0          0.0
  3        0.0         0.0          0.0          0.0          0.0          0.0
  4        0.0         0.0          0.0          0.0          0.0          0.0
  5        0.0         0.0          0.0          0.0          0.0          0.0
  6        0.0         0.0          0.0          0.0          0.0          0.0
  7        0.0         0.0          0.0          0.0          0.0          0.0
  8        0.0         0.0          0.0          0.0          0.0          0.0
  9        0.0         0.0          0.0          0.0          0.0          0.0
 10        0.0         0.0          0.0          0.0          0.0          0.0
 11        0.0         0.0          0.0          0.0          0.0          0.0
 12        0.0         0.0          0.0          0.0          0.0          0.0
 13        0.0         0.0          0.0          0.0          0.0          0.0
 14        0.0         0.0          0.0          0.0          0.0          0.0
 15        0.0         0.0          0.0          0.0          0.0          0.0
 16        0.0         0.0          0.0          0.0          0.0          0.0

                            THE JOINT FREQUENCY FUNCTION FOR STABILITY CLASS  6

  1        0.0         0.0          0.0          0.0          0.0          0.0
  2        0.0         0.0          0.0          0.0          0.0          0.0
  3        0.0         0.0          0.0          0.0          0.0          0.0
  4        0.0         0.0          0.0          0.0          0.0          0.0
  5        0.0         0.0          0.0          0.0          0.0          0.0
  6        0.0         0.0          0.0          0.0          0.0          0.0
  7        0.0         0.0          0.0          0.0          0.0          0.0
  8        0.0         0.0          0.0          0.0          0.0          0.0
  9        0.0         0.0          0.0          0.0          0.0          0.0
 10        0.0         0.0          0.0          0.0          0.0          0.0
 11        0.0         0.0          0.0          0.0          0.0          0.0
 12        0.0         0.0          0.0          0.0          0.0          0.0
 13        0.0         0.0          0.0          0.0          0.0          0.0
 14        0.0         0.0          0.0          0.0          0.0          0.0
 15        0.0         0.0          0.0          0.0          0.0          0.0
 16        0.0         0.0          0.0          0.0          0.0          0.0
```

Table A-2 (continued). OUTPUT FOR TEST EXAMPLE, INPUT PARAMETERS USED

```
SOURCE INPUT                         COM VERSION 72313.  RUN 99999
       X           Y            TX           S1           S2           SH           U            VS           T            SA
 0.50000E 01  0.50000E 01  0.10000E 05  0.40000E 04  0.40000E 04  0.20000E 02 0.0          0.0          0.0          0.0
 0.50000E 01  0.15000E 02  0.50000E 04  0.10000E 04  0.10000E 04  0.20000E 02 0.0          0.0          0.0          0.0
 0.10000E 02  0.15000E 02  0.50000E 04  0.10000E 04  0.10000E 04  0.20000E 02 0.0          0.0          0.0          0.0
 0.15000E 02  0.15000E 02  0.50000E 04  0.10000E 04  0.10000E 04  0.20000E 02 0.0          0.0          0.0          0.0
 0.15000E 02  0.10000E 02  0.50000E 04  0.10000E 04  0.10000E 04  0.20000E 02 0.0          0.0          0.0          0.0
 0.15000E 02  0.50000E 01  0.50000E 04  0.10000E 04  0.10000E 04  0.20000E 02 0.0          0.0          0.0          0.0
 0.12500E 02  0.12500E 02  0.0          0.10000E 04  0.10000E 04  0.20000E 02 0.10000E 01 0.50000E 01 0.20000E 02 0.0

        6 AREA SOURCES.          1 POINT SOURCES.
```

Table A-3. OUTPUT OF TEST EXAMPLE, COMPUTED CONCENTRATIONS

```
                              CDM VERSION 72313.  RUN 99999
                              (MICROGRAMS PER CUBIC METER)
                                          POINT              TOTAL              CALIBRATED              OBSERVED
                        AREA
                     P 1       P 2       P 1       P 2       P 1       P 2       P 1       P 2       P 1        P 2
   COORDINATES
   5.00      5.00    304.      349.      31.       45.       334.      394.      334.      394.      0          0
AREA  ROSES
   A P1   39   61   64   61   39    4    4    4    4    4    4    4    4    4    4    4  500  500
   A P2   45   71   76   71   45    4    4    4    4    4    4    4    4    4    4    4  500  500
POINT ROSES
   P P1    0    0   31    0    0    0    0    0    0    0    0    0    0    0    0    0  500  500
   P P2    0    0   45    0    0    0    0    0    0    0    0    0    0    0    0    0  500  500
   5.00      6.25    406.      454.      36.       52.       443.      506.      443.      506.      0          0
   5.00      7.50    443.      495.      43.       59.       487.      554.      487.      554.      0          0
   5.00      8.75    460.      512.      48.       64.       507.      577.      507.      577.      0          0
   5.00     10.00    474.      529.      53.       70.       527.      599.      527.      599.      0          0
   5.00     11.25    477.      532.      58.       76.       535.      608.      535.      608.      0          0
   5.00     12.50    478.      533.      58.       76.       536.      609.      536.      609.      0          0
   5.00     13.75    477.      532.      58.       76.       535.      608.      535.      608.      0          0
   5.00     15.00    474.      529.      53.       70.       527.      599.      527.      599.      0          0
   5.00     16.25    460.      512.      48.       64.       507.      577.      507.      577.      0          0
   5.00     17.50    443.      495.      43.       59.       487.      554.      487.      554.      0          0
   5.00     18.75    406.      454.      36.       52.       443.      506.      443.      506.      0          0
   5.00     20.00    304.      349.      31.       45.       334.      394.      334.      394.      0          0
AREA  ROSES
   A P1    4    4    4    4   39   61   64   61   39    4    4    4    4    4    4    4  500 2000
   A P2    4    4    4    4   45   71   76   71   45    4    4    4    4    4    4    4  500 2000
POINT ROSES
   P P1    0    0    0    0    0    0   31    0    0    0    0    0    0    0    0    0  500 2000
   P P2    0    0    0    0    0    0   45    0    0    0    0    0    0    0    0    0  500 2000
   6.25      5.00    406.      454.      36.       52.       443.      506.      443.      506.      0          0
   6.25      6.25    585.      637.      43.       59.       628.      697.      628.      697.      0          0
   6.25      7.50    636.      693.      52.       69.       688.      762.      688.      762.      0          0
   6.25      8.75    656.      715.      62.       80.       718.      795.      718.      795.      0          0
   6.25     10.00    674.      735.      70.       89.       743.      824.      743.      824.      0          0
   6.25     11.25    678.      739.      79.       99.       756.      838.      756.      838.      0          0
   6.25     12.50    679.      741.      79.       99.       758.      840.      758.      840.      0          0
   6.25     13.75    678.      739.      79.       99.       756.      838.      756.      838.      0          0
   6.25     15.00    674.      735.      70.       89.       743.      824.      743.      824.      0          0
   6.25     16.25    656.      715.      62.       80.       718.      795.      718.      795.      0          0
   6.25     17.50    636.      693.      52.       69.       688.      762.      688.      762.      0          0
   6.25     18.75    585.      637.      43.       59.       628.      697.      628.      697.      0          0
   6.25     20.00    406.      454.      36.       52.       443.      506.      443.      506.      0          0
   7.50      5.00    443.      495.      43.       59.       487.      554.      487.      554.      0          0
   7.50      6.25    636.      693.      52.       69.       688.      762.      688.      762.      0          0
   7.50      7.50    696.      758.      64.       83.       760.      841.      760.      841.      0          0
   7.50      8.75    721.      785.      80.      100.       801.      885.      801.      885.      0          0
```

Table A-3 (continued). OUTPUT OF TEST EXAMPLE, COMPUTED CONCENTRATIONS

```
                                          CDM VERSION 72313.  RUN 99999
                                          (MICROGRAMS PER CUBIC METER)
                              AREA                 POINT                     TOTAL               CALIBRATED              OBSERVED
 COORDINATES              P 1        P 2        P 1        P 2        P 1        P 2        P 1        P 2         P 1        P 2
  7.50    10.00          741.       809.        95.       116.       836.       925.       836.       925.         0          0
  7.50    11.25          745.       813.       110.       132.       855.       945.       855.       945.         0          0
  7.50    12.50          747.       814.       114.       136.       860.       951.       860.       951.         0          0
  7.50    13.75          745.       813.       110.       132.       855.       945.       855.       945.         0          0
  7.50    15.00          741.       809.        95.       116.       836.       925.       836.       925.         0          0
  7.50    16.25          721.       785.        80.       100.       801.       885.       801.       885.         0          0
  7.50    17.50          696.       758.        64.        83.       760.       841.       760.       841.         0          0
  7.50    18.75          636.       693.        52.        69.       688.       762.       688.       762.         0          0
  7.50    20.00          443.       495.        43.        59.       487.       554.       487.       554.         0          0
  8.75     5.00          460.       512.        46.        64.       507.       577.       507.       577.         0          0
  8.75     6.25          656.       715.        62.        80.       718.       795.       718.       795.         0          0
  8.75     7.50          721.       785.        80.       100.       801.       885.       801.       885.         0          0
  8.75     8.75          749.       816.       103.       125.       852.       941.       852.       941.         0          0
  8.75    10.00          770.       841.       138.       162.       908.      1003.       908.      1003.         0          0
  8.75    11.25          775.       846.       165.       191.       941.      1037.       941.      1037.         0          0
  8.75    12.50          777.       848.       179.       205.       956.      1053.       956.      1053.         0          0
  8.75    13.75          775.       846.       165.       191.       941.      1037.       941.      1037.         0          0
  8.75    15.00          770.       841.       138.       162.       908.      1003.       908.      1003.         0          0
  8.75    16.25          744.       816.       103.       125.       852.       941.       852.       941.         0          0
  8.75    17.50          721.       785.        80.       100.       801.       885.       801.       885.         0          0
  8.75    18.75          656.       715.        62.        80.       718.       795.       718.       795.         0          0
  8.75    20.00          460.       512.        48.        64.       507.       577.       507.       577.         0          0
 10.00     5.00          474.       529.        53.        70.       527.       599.       527.       599.         0          0
 10.00     6.25          674.       735.        70.        89.       743.       824.       743.       824.         0          0
 10.00     7.50          741.       809.        95.       116.       836.       925.       836.       925.         0          0
 10.00     8.75          770.       841.       138.       162.       908.      1003.       908.      1003.         0          0
 10.00    10.00          792.       867.       197.       224.       990.      1091.       990.      1091.         0          0
 10.00    11.25          798.       873.       286.       316.      1084.      1188.      1084.      1188.         0          0
 10.00    12.50          801.       876.       337.       368.      1137.      1244.      1137.      1244.         0          0
 10.00    13.75          798.       873.       286.       316.      1084.      1188.      1084.      1188.         0          0
 10.00    15.00          792.       867.       197.       224.       990.      1091.       990.      1091.         0          0
 10.00    16.25          770.       841.       138.       162.       908.      1003.       908.      1003.         0          0
 10.00    17.50          741.       809.        95.       116.       836.       925.       836.       925.         0          0
 10.00    18.75          674.       735.        70.        89.       743.       824.       743.       824.         0          0
 10.00    20.00          474.       529.        53.        70.       527.       599.       527.       599.         0          0
 11.25     5.00          477.       532.        58.        76.       535.       608.       535.       608.         0          0
 11.25     6.25          678.       739.        79.        99.       756.       838.       756.       838.         0          0
 11.25     7.50          745.       813.       110.       132.       855.       945.       855.       945.         0          0
 11.25     8.75          775.       846.       165.       191.       941.      1037.       941.      1037.         0          0
 11.25    10.00          798.       873.       286.       316.      1084.      1188.      1084.      1188.         0          0
 11.25    11.25          804.       879.       555.       591.      1359.      1470.      1359.      1470.         0          0
 11.25    12.50          807.       883.       884.       924.      1691.      1807.      1691.      1807.         0          0
```

Table A-3 (continued). OUTPUT OF TEST EXAMPLE, COMPUTED CONCENTRATIONS

CUM VERSION 72313, RUN 99999
(MICROGRAMS PER CUBIC METER)

		AREA		POINT		TOTAL		CALIBRATED		OBSERVED	
COORDINATES		P 1	P 2	P 1	P 2	P 1	P 2	P 1	P 2	P 1	P 2
11.25	13.75	804.	879.	555.	591.	1359.	1470.	1359.	1470.	0	0
11.25	15.00	798.	873.	286.	316.	1084.	1188.	1084.	1188.	0	0
11.25	16.25	775.	846.	165.	191.	941.	1037.	941.	1037.	0	0
11.25	17.50	745.	813.	110.	132.	855.	945.	855.	945.	0	0
11.25	18.75	678.	739.	79.	99.	756.	838.	756.	838.	0	0
11.25	20.00	477.	532.	58.	76.	535.	608.	535.	608.	0	0
12.50	5.00	478.	533.	58.	76.	536.	609.	536.	609.	0	0
12.50	6.25	679.	741.	79.	99.	758.	840.	758.	840.	0	0
12.50	7.50	747.	814.	114.	136.	860.	951.	860.	951.	0	0
12.50	8.75	777.	848.	179.	205.	956.	1053.	956.	1053.	0	0
12.50	10.00	801.	876.	337.	368.	1137.	1244.	1137.	1244.	0	0
12.50	11.25	807.	883.	884.	924.	1691.	1807.	1691.	1807.	0	0
12.50	12.50	810.	886.	0.	0.	810.	886.	810.	886.	0	0
12.50	13.75	807.	883.	884.	924.	1691.	1807.	1691.	1807.	0	0
12.50	15.00	801.	876.	337.	368.	1137.	1244.	1137.	1244.	0	0
12.50	16.25	777.	848.	179.	205.	956.	1053.	956.	1053.	0	0
12.50	17.50	747.	814.	114.	136.	860.	951.	860.	951.	0	0
12.50	18.75	679.	741.	79.	99.	758.	840.	758.	840.	0	0
12.50	20.00	478.	533.	58.	76.	536.	609.	536.	609.	0	0
13.75	5.00	477.	532.	58.	76.	535.	608.	535.	608.	0	0
13.75	6.25	678.	739.	79.	99.	756.	838.	756.	838.	0	0
13.75	7.50	745.	813.	110.	132.	855.	945.	855.	945.	0	0
13.75	8.75	775.	846.	165.	191.	941.	1037.	941.	1037.	0	0
13.75	10.00	798.	873.	286.	316.	1084.	1188.	1084.	1188.	0	0
13.75	11.25	804.	879.	555.	591.	1359.	1470.	1359.	1470.	0	0
13.75	12.50	807.	883.	884.	924.	1691.	1807.	1691.	1807.	0	0
13.75	13.75	804.	879.	555.	591.	1359.	1470.	1359.	1470.	0	0
13.75	15.00	798.	873.	286.	316.	1084.	1188.	1084.	1188.	0	0
13.75	16.25	775.	846.	165.	191.	941.	1037.	941.	1037.	0	0
13.75	17.50	745.	813.	110.	132.	855.	945.	855.	945.	0	0
13.75	18.75	678.	739.	79.	99.	756.	838.	756.	838.	0	0
13.75	20.00	477.	532.	58.	76.	535.	608.	535.	608.	0	0
15.00	5.00	474.	529.	53.	70.	527.	599.	527.	599.	0	0
15.00	6.25	674.	735.	70.	89.	743.	824.	743.	824.	0	0
15.00	7.50	741.	809.	95.	116.	836.	925.	836.	925.	0	0
15.00	8.75	770.	841.	138.	162.	908.	1003.	908.	1003.	0	0
15.00	10.00	792.	867.	197.	224.	990.	1091.	990.	1091.	0	0
15.00	11.25	798.	873.	286.	316.	1084.	1188.	1084.	1188.	0	0
15.00	12.50	801.	876.	337.	368.	1137.	1244.	1137.	1244.	0	0
15.00	13.75	798.	873.	286.	316.	1084.	1188.	1084.	1188.	0	0
15.00	15.00	792.	867.	197.	224.	990.	1091.	990.	1091.	0	0
15.00	16.25	770.	841.	138.	162.	908.	1003.	908.	1003.	0	0

Table A-3 (continued). OUTPUT OF TEST EXAMPLE, COMPUTED CONCENTRATIONS

```
                                       COM VERSION 72313.  RUN 99999
                                       (MICROGRAMS PER CUBIC METER)
                            AREA                POINT               TOTAL               CALIBRATED             OBSERVED
  COORDINATES           P 1       P 2       P 1       P 2       P 1       P 2       P 1       P 2         P 1       P 2
 15.00     17.50        741.      809.       95.      116.      836.      925.      836.      925.          0         0
 15.00     18.75        674.      735.       70.       89.      743.      824.      743.      824.          0         0
 15.00     20.00        474.      529.       53.       70.      527.      599.      527.      549.          0         0
 16.25      5.00        460.      512.       48.       64.      507.      577.      507.      577.          0         0
 16.25      6.25        656.      715.       62.       80.      718.      745.      718.      795.          0         0
 16.25      7.50        721.      785.       80.      100.      801.      885.      801.      885.          0         0
 16.25      8.75        749.      816.      103.      125.      852.      941.      852.      941.          0         0
 16.25     10.00        770.      841.      138.      162.      908.     1003.      908.     1003.          0         0
 16.25     11.25        775.      846.      165.      191.      941.     1037.      941.     1037.          0         0
 16.25     12.50        777.      848.      179.      205.      956.     1053.      956.     1053.          0         0
 16.25     13.75        775.      846.      165.      191.      941.     1037.      941.     1037.          0         0
 16.25     15.00        770.      841.      138.      162.      908.     1003.      908.     1003.          0         0
 16.25     16.25        749.      816.      103.      125.      852.      941.      852.      941.          0         0
 16.25     17.50        721.      785.       80.      100.      801.      885.      801.      885.          0         0
 16.25     18.75        656.      715.       62.       80.      718.      795.      718.      795.          0         0
 16.25     20.00        460.      512.       48.       64.      507.      577.      507.      577.          0         0
 17.50      5.00        443.      495.       43.       59.      487.      554.      487.      554.          0         0
 17.50      6.25        636.      693.       52.       69.      688.      762.      688.      762.          0         0
 17.50      7.50        696.      758.       64.       83.      760.      841.      760.      841.          0         0
 17.50      8.75        721.      785.       80.      100.      801.      885.      801.      885.          0         0
 17.50     10.00        741.      809.       95.      116.      836.      925.      836.      925.          0         0
 17.50     11.25        745.      813.      110.      132.      855.      945.      855.      945.          0         0
 17.50     12.50        747.      814.      114.      136.      860.      951.      860.      951.          0         0
 17.50     13.75        745.      813.      110.      132.      855.      945.      855.      945.          0         0
 17.50     15.00        741.      809.       95.      116.      836.      925.      836.      925.          0         0
 17.50     16.25        721.      785.       80.      100.      801.      885.      801.      885.          0         0
 17.50     17.50        696.      758.       64.       83.      760.      841.      760.      841.          0         0
 17.50     18.75        636.      693.       52.       69.      688.      762.      688.      762.          0         0
 17.50     20.00        443.      495.       43.       59.      487.      554.      487.      554.          0         0
 18.75      5.00        406.      454.       36.       52.      443.      506.      443.      506.          0         0
 18.75      6.25        585.      637.       43.       59.      628.      697.      628.      697.          0         0
 18.75      7.50        636.      693.       52.       69.      688.      762.      688.      762.          0         0
 18.75      8.75        656.      715.       62.       80.      718.      795.      718.      795.          0         0
 18.75     10.00        674.      735.       70.       89.      743.      824.      743.      824.          0         0
 18.75     11.25        678.      739.       74.       99.      756.      838.      756.      838.          0         0
 18.75     12.50        679.      741.       79.       99.      758.      840.      758.      840.          0         0
 18.75     13.75        678.      739.       79.       99.      756.      838.      756.      838.          0         0
 18.75     15.00        674.      735.       70.       89.      743.      824.      743.      824.          0         0
 18.75     16.25        656.      715.       62.       80.      718.      795.      718.      795.          0         0
 18.75     17.50        636.      693.       52.       69.      688.      762.      688.      762.          0         0
 18.75     18.75        585.      637.       43.       59.      628.      697.      628.      697.          0         0
 18.75     20.00        406.      454.       36.       52.      443.      506.      443.      506.          0         0
 20.00      5.00        304.      349.       31.       45.      334.      394.      334.      394.          0         0
```

Table A-3 (continued). OUTPUT OF TEST EXAMPLE, COMPUTED CONCENTRATIONS

```
                                        CDM VERSION 72313, RUN 99999
                                        (MICROGRAMS PER CUBIC METER)
                           AREA               POINT               TOTAL               CALIBRATED               OBSERVED
      COORDINATES       P 1      P 2       P 1      P 2       P 1      P 2       P 1         P 2         P 1         P 2
AREA  ROSES
      A P1   39    4    4    4    4    4    4    4    4    4    4    4   39   61   64   61 2000  500
      A P2   45    4    4    4    4    4    4    4    4    4    4    4   45   71   76   71 2000  500
POINT ROSES
      P P1    0    0    0    0    0    0    0    0    0    0    0    0    0    0   31    0 2000  500
      P P2    0    0    0    0    0    0    0    0    0    0    0    0    0    0   45    0 2000  500
    20.00      6.25     406.     454.      36.      52.     443.     506.     443.       506.          0           0
    20.00      7.50     443.     495.      43.      59.     487.     554.     487.       554.          0           0
    20.00      8.75     460.     512.      48.      64.     507.     577.     507.       577.          0           0
    20.00     10.00     474.     529.      53.      70.     527.     599.     527.       599.          0           0
    20.00     11.25     477.     532.      58.      76.     535.     608.     535.       608.          0           0
    20.00     12.50     478.     533.      58.      76.     536.     609.     536.       609.          0           0
    20.00     13.75     477.     532.      58.      76.     535.     608.     535.       608.          0           0
    20.00     15.00     474.     529.      53.      70.     527.     599.     527.       599.          0           0
    20.00     16.25     460.     512.      48.      64.     507.     577.     507.       577.          0           0
    20.00     17.50     443.     495.      43.      59.     487.     554.     487.       554.          0           0
    20.00     18.75     406.     454.      36.      52.     443.     506.     443.       506.          0           0
    20.00     20.00     304.     349.      31.      45.     334.     344.     334.       344.          0           0
AREA  ROSES
      A P1    4    4    4    4    4    4    4    4   39   61   64   61   39    4    4    4 2000 2000
      A P2    4    4    4    4    4    4    4    4   45   71   76   71   45    4    4    4 2000 2000
POINT ROSES
      P P1    0    0    0    0    0    0    0    0    0    0   31    0    0    0    0    0 2000 2000
      P P2    0    0    0    0    0    0    0    0    0    0   45    0    0    0    0    0 2000 2000
```

Table A-4. FORMAT OF CARD OUTPUT

Card	Column	Format	Contents
1	1 to 8	F8.2	PUX (X coordinate of receptor in plotting grid units)
	9 to 14	F6.2	PUY (Y coordinate of receptor in plotting grid units)
	15 to 18	I4	KPX(1) (Area concentration for first pollutant)
	19 to 22	I4	(2) (Area concentration for second pollutant)
	23 to 26	I4	(3)(Point concentration for first pollutant)
	27 to 30	I4	(4) (Point concentration for second pollutant)
	31 to 34	I4	(5) (Total concentration for first pollutant)
	35 to 38	I4	(6) (Total concentration for second pollutant)
	39 to 42	I4	(7) (Calibrated total concentration for first pollutant)
	43 to 46	I4	(8) (Calibrated total concentration for second pollutant)
	47 to 50	I4	(9) (Observed concentration of first pollutant)
	51 to 54	I4	(10) (Observed concentration of second pollutant)
	56 to 64	F10.2	RX (X map coordinate of receptor)
	65 to 74	F10.2	RY (Y map coordinate of receptor)
	75 to 79	I5	IRUN (Computer run identification number)
	80		1 (Card identifier)
2[a]	1 to 4	A4	AROS(1) (Card identifier)
	5 to 68	16I4	KPX(1)-KPX(16) (Area concentration by wind direction)
	69 to 74	I6	RX (X map coordinate of receptor multiplied by 100 to remove decimals
	75 to 80	I6	RY (Y map coordinate of receptor multiplied by 100 to remove decimals)

Table A-4 (continued). FORMAT OF CARD OUTPUT

Card	Column	Format	Contents
3[a]	--	--	(Same as Card 2 for second pollutant)
4[a]	1 to 4	A4	PROS(1) (Card identifier)
	5 to 68	16I4	KPX(1)-KPX(16) (Point concentration by wind direction)
	69 to 74	I6	RX (X map coordinate of receptor multiplied by 100 to remove decimals)
	75 to 80	I6	RY (Y map coordinate of receptor multiplied by 100 to remove decimals)
5[a]	--	--	(Same as Card 4 for second pollutant)

[a] Cards only punched if NROSE greater than zero.

Table A-5. LISTING OF CARD OUTPUT FOR TEST EXAMPLE

```
      0.50  0.50 304 349  31  45 334  394 334  394   0   0         5.00        5.00 99999I
A P1   39  61  64  61  39   4   4    4   4    4   4   4   4   4   4   4   500   500
A P2   45  71  76  71  45   4   4    4   4    4   4   4   4   4   4   4   500   500
P P1    0   0  31   0   0   0   0    0   0    0   0   0   0   0   0   0   500   500
P P2    0   0  45   0   0   0   0    0   0    0   0   0   0   0   0   0   500   500
      0.50  0.75 406 454  36  52 443  506 443  506   0   0         5.00        6.25 99999I
      0.50  1.00 443 495  43  59 487  554 487  554   0   0         5.00        7.50 99999I
      0.50  1.25 460 512  48  64 507  577 507  577   0   0         5.00        8.75 99999I
      0.50  1.50 474 529  53  70 527  599 527  599   0   0         5.00       10.00 99999I
      0.50  1.75 477 532  58  76 535  608 535  608   0   0         5.00       11.25 99999I
      0.50  2.00 478 533  58  76 536  609 536  609   0   0         5.00       12.50 99999I
      0.50  2.25 477 532  58  76 535  608 535  608   0   0         5.00       13.75 99999I
      0.50  2.50 474 529  53  70 527  599 527  599   0   0         5.00       15.00 99999I
      0.50  2.75 460 512  48  64 507  577 507  577   0   0         5.00       16.25 99999I
      0.50  3.00 443 495  43  59 487  554 487  554   0   0         5.00       17.50 99999I
      0.50  3.25 406 454  36  52 443  506 443  506   0   0         5.00       18.75 99999I
      0.50  3.50 304 349  31  45 334  394 334  394   0   0         5.00       20.00 99999I
A P1    4   4   4   4  39  61  64   61  39    4   4   4   4   4   4   4   500  2000
A P2    4   4   4   4  45  71  76   71  45    4   4   4   4   4   4   4   500  2000
P P1    0   0   0   0   0   0  31    0   0    0   0   0   0   0   0   0   500  2000
P P2    0   0   0   0   0   0  45    0   0    0   0   0   0   0   0   0   500  2000
      0.75  0.50 406 454  36  52 443  506 443  506   0   0         6.25        5.00 99999I
      0.75  0.75 585 637  43  59 628  697 628  697   0   0         6.25        6.25 99999I
      0.75  1.00 636 693  52  69 688  762 688  762   0   0         6.25        7.50 99999I
      0.75  1.25 656 715  62  80 718  795 718  795   0   0         6.25        8.75 99999I
      0.75  1.50 674 735  70  89 743  824 743  824   0   0         6.25       10.00 99999I
      0.75  1.75 678 739  79  99 756  838 756  838   0   0         6.25       11.25 99999I
      0.75  2.00 679 741  79  99 758  840 758  840   0   0         6.25       12.50 99999I
      0.75  2.25 678 739  79  99 756  838 756  838   0   0         6.25       13.75 99999I
      0.75  2.50 674 735  70  89 743  824 743  824   0   0         6.25       15.00 99999I
      0.75  2.75 656 715  62  80 718  795 718  795   0   0         6.25       16.25 99999I
      0.75  3.00 636 693  52  69 688  762 688  762   0   0         6.25       17.50 99999I
      0.75  3.25 585 637  43  59 628  697 628  697   0   0         6.25       18.75 99999I
      0.75  3.50 406 454  36  52 443  506 443  506   0   0         6.25       20.00 99999I
      1.00  0.50 443 495  43  59 487  554 487  554   0   0         7.50        5.00 99999I
      1.00  0.75 636 693  52  69 688  762 688  762   0   0         7.50        6.25 99999I
      1.00  1.00 696 758  64  83 760  841 760  841   0   0         7.50        7.50 99999I
      1.00  1.25 721 785  80 100 801  885 801  885   0   0         7.50        8.75 99999I
      1.00  1.50 741 809  95 116 836  925 836  925   0   0         7.50       10.00 99999I
      1.00  1.75 745 813 110 132 855  945 855  945   0   0         7.50       11.25 99999I
      1.00  2.00 747 814 114 136 860  951 860  951   0   0         7.50       12.50 99999I
      1.00  2.25 745 813 110 132 855  945 855  945   0   0         7.50       13.75 99999I
      1.00  2.50 741 809  95 116 836  925 836  925   0   0         7.50       15.00 99999I
      1.00  2.75 721 785  80 100 801  885 801  885   0   0         7.50       16.25 99999I
      1.00  3.00 696 758  64  83 760  841 760  841   0   0         7.50       17.50 99999I
      1.00  3.25 636 693  52  69 688  762 688  762   0   0         7.50       18.75 99999I
      1.00  3.50 443 495  43  59 487  554 487  554   0   0         7.50       20.00 99999I
      1.25  0.50 460 512  48  64 507  577 507  577   0   0         8.75        5.00 99999I
      1.25  0.75 656 715  62  80 718  795 718  795   0   0         8.75        6.25 99999I
      1.25  1.00 721 785  80 100 801  885 801  885   0   0         8.75        7.50 99999I
      1.25  1.25 749 816 103 125 852  941 852  941   0   0         8.75        8.75 99999I
      1.25  1.50 770 841 138 162 908 1003 908 1003   0   0         8.75       10.00 99999I
      1.25  1.75 775 846 165 191 941 1037 941 1037   0   0         8.75       11.25 99999I
      1.25  2.00 777 848 179 205 956 1053 956 1053   0   0         8.75       12.50 99999I
      1.25  2.25 775 846 165 191 941 1037 941 1037   0   0         8.75       13.75 99999I
      1.25  2.50 770 841 138 162 908 1003 908 1003   0   0         8.75       15.00 99999I
      1.25  2.75 749 816 103 125 852  941 852  941   0   0         8.75       16.25 99999I
      1.25  3.00 721 785  80 100 801  885 801  885   0   0         8.75       17.50 99999I
      1.25  3.25 656 715  62  80 718  795 718  795   0   0         8.75       18.75 99999I
      1.25  3.50 460 512  48  64 507  577 507  577   0   0         8.75       20.00 99999I
      1.50  0.50 474 529  53  70 527  599 527  599   0   0        10.00        5.00 99999I
      1.50  0.75 674 735  70  89 743  824 743  824   0   0        10.00        6.25 99999I
      1.50  1.00 741 809  95 116 836  925 836  925   0   0        10.00        7.50 99999I
      1.50  1.25 770 841 138 162 908 1003 908 1003   0   0        10.00        8.75 99999I
```

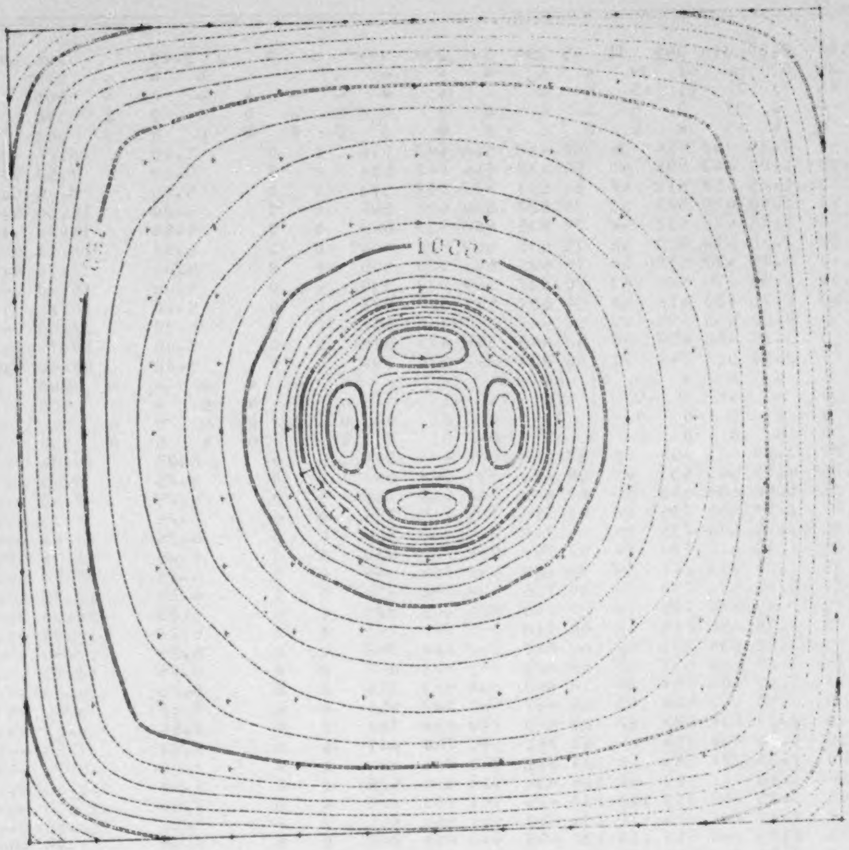


Figure A-2. Isopleth for test example.

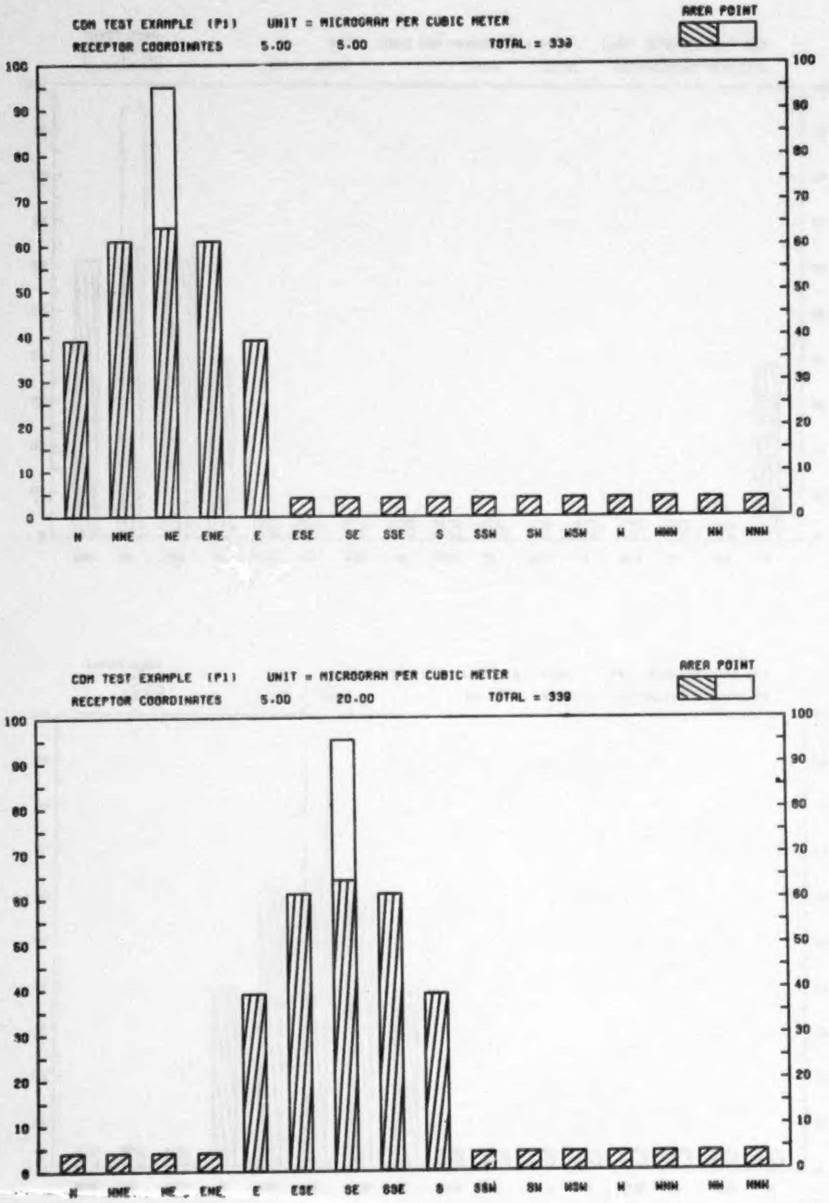
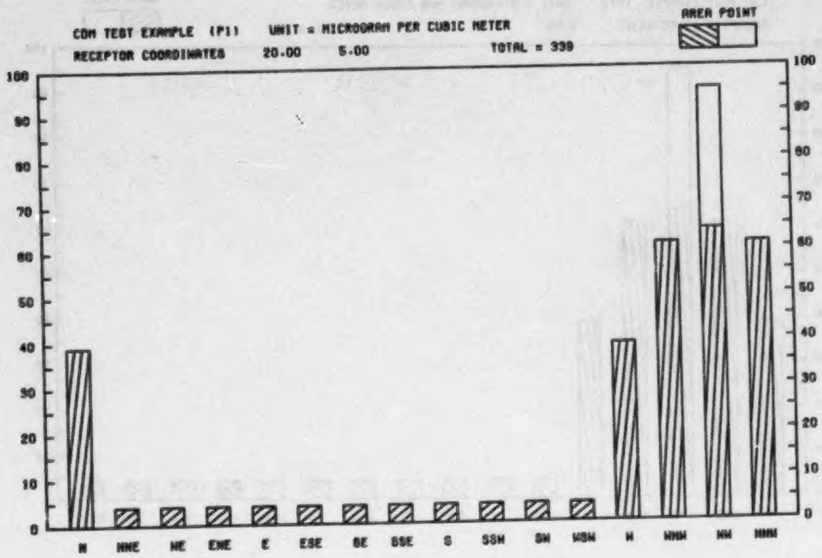


Figure A-3. Histograms for test example.



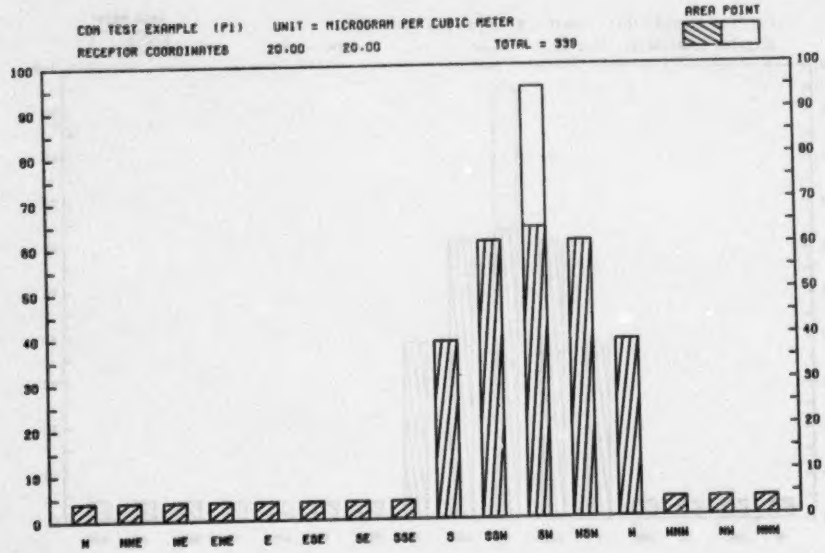


Figure A-3 (continued). Histograms for test example.

APPENDIX B. FLOW DIAGRAMS

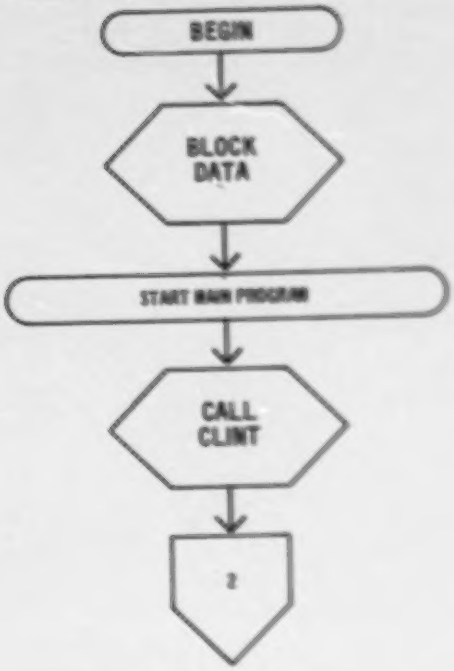

BEGIN
BLOCK DATA
START MAIN PROGRAM
CALL CLINT
2

Figure B-1. Abbreviated flow chart of Climatological Dispersion Model.

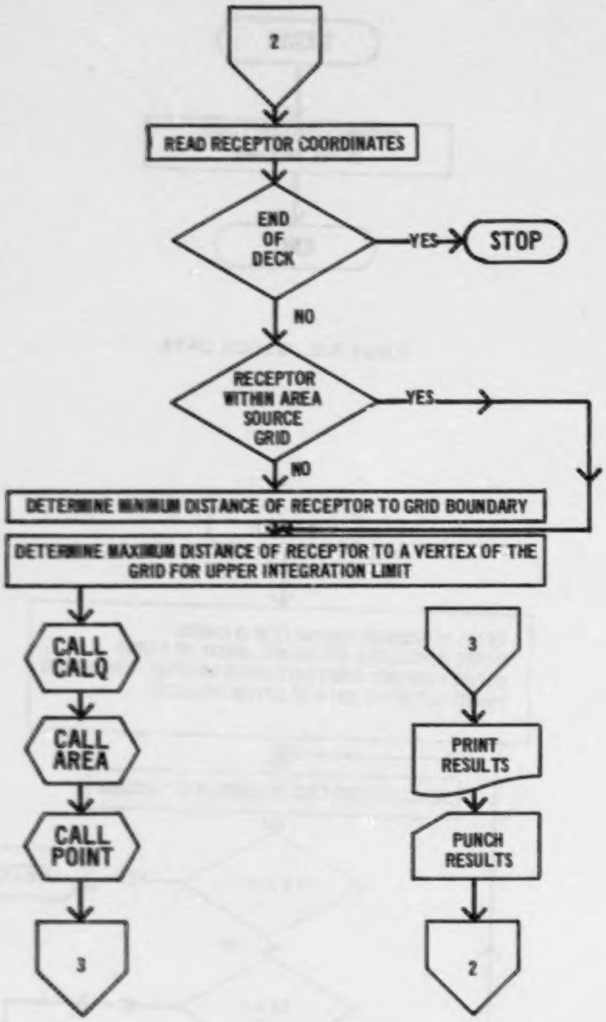

2
READ RECEPTOR COORDINATES
END OF DECK
YES
STOP
NO
RECEPTOR WITHIN AREA SOURCE GRID
YES
NO
DETERMINE MINIMUM DISTANCE OF RECEPTOR TO GRID BOUNDARY
DETERMINE MAXIMUM DISTANCE OF RECEPTOR TO A VERTEX OF THE GRID FOR UPPER INTEGRATION LIMIT
CALL CALQ
CALL AREA
CALL POINT
3
3
PRINT RESULTS
PUNCH RESULTS
2

Figure B-1 (continued). Abbreviated flow chart of Climatological Dispersion Model.

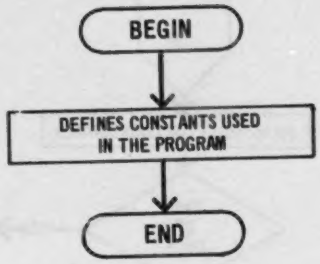

BEGIN
DEFINES CONSTANTS USED IN THE PROGRAM
END

Figure B-2. BLOCK DATA

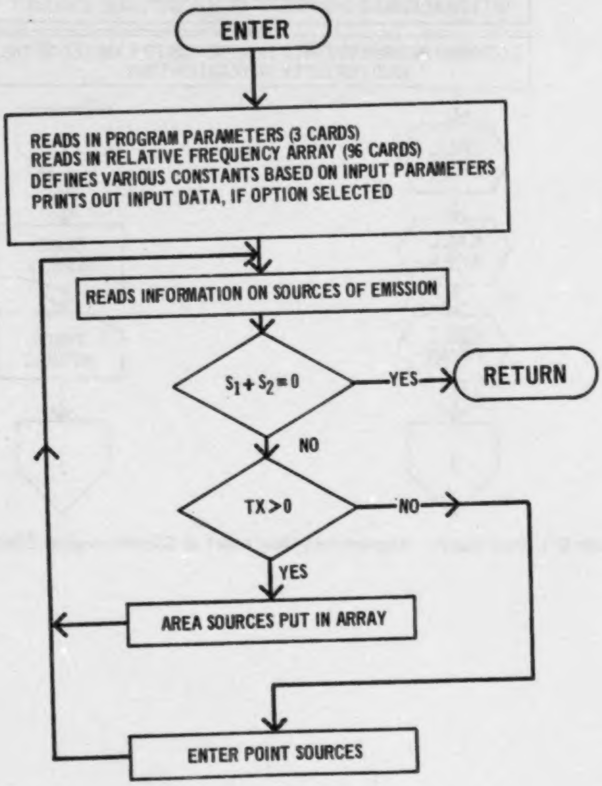

ENTER
READS IN PROGRAM PARAMETERS (3 CARDS)
READS IN RELATIVE FREQUENCY ARRAY (96 CARDS)
DEFINES VARIOUS CONSTANTS BASED ON INPUT PARAMETERS
PRINTS OUT INPUT DATA, IF OPTION SELECTED
READS INFORMATION ON SOURCES OF EMISSION
S1 + S2 = 0
YES
RETURN
NO
TX > 0
NO
YES
AREA SOURCES PUT IN ARRAY
ENTER POINT SOURCES

Figure B-3. Subroutine CLINT.

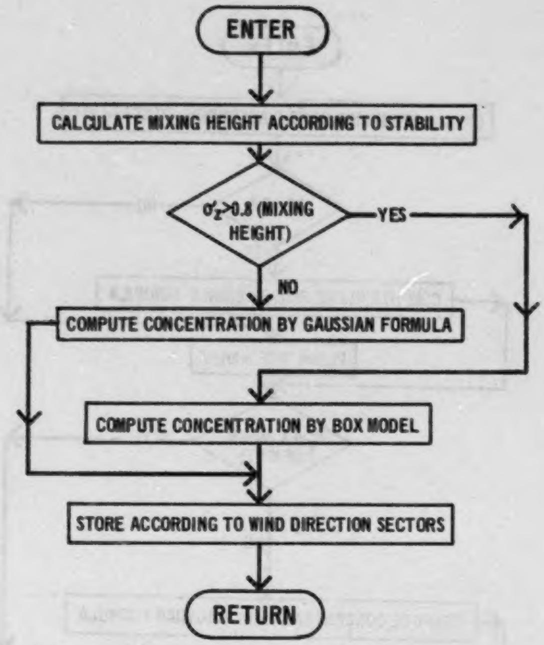

ENTER
CALCULATE MIXING HEIGHT ACCORDING TO STABILITY
σ_z>0.8 (MIXING HEIGHT)
YES
NO
COMPUTE CONCENTRATION BY GAUSSIAN FORMULA
COMPUTE CONCENTRATION BY BOX MODEL
STORE ACCORDING TO WIND DIRECTION SECTORS
RETURN

Figure B-4. Subroutine AREA.

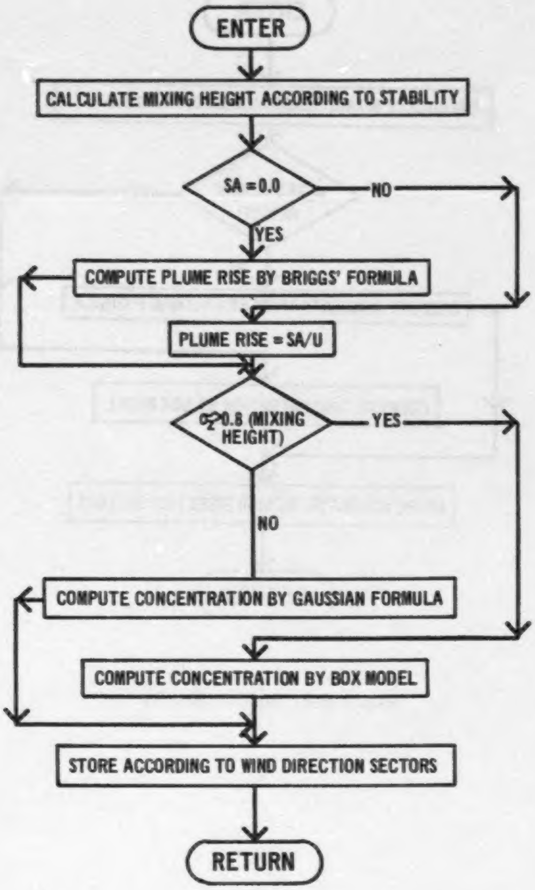

ENTER
CALCULATE MIXING HEIGHT ACCORDING TO STABILITY
SA = 0.0
NO
YES
COMPUTE PLUME RISE BY BRIGGS' FORMULA
PLUME RISE = SA/U
$\sigma_z \geq 0.8$ (MIXING HEIGHT)
YES
NO
COMPUTE CONCENTRATION BY GAUSSIAN FORMULA
COMPUTE CONCENTRATION BY BOX MODEL
STORE ACCORDING TO WIND DIRECTION SECTORS
RETURN

Figure B-5. Subroutine POINT.

APPENDIX C. FORTRAN STATEMENTS

Table C-1. FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

MAIN

```
      COMMON /C1/ K,MX,MN,HT,F(6,6,16),G(6,5),U(6),RI,RJ,INC(4),DELR
      COMMON /C2/ UE(6),YD,YN,TMN,HMIN,DINT,YCON,TA(4),IPG,XG,YG,IRD
      COMMON /C3/ RATG,IRUN,CA(2),CB(2),TK(16),AROS(2),PROS(2),TANG
      COMMON /C4/ DECAY(2),ICA(6),ICP(6),H(6),HX(6),GB(2),NO,IVER,IWR
      COMMON /C5/ Q(100,4),GA(2),IAD(4,5),XGG,YGG,IAS,TDA,TDB,TDC,IPU
      COMMON /QCOM/ N,DR,IX,IY,TT(16,21),KTC,IXX,IYY,RAD,Z(50,50,3),TD
      COMMON /ACOM/ PI,SZA(6),ABAR(2),AROSE(16,2),XS(6)
      COMMON /PCOM/ PH(200),PR(200),PS(200,4),PX(200),PY(200),FB(200),
     *XX(200),DHF(200),WA(16),WB(16),PROSE(16,2),CV,IPS,RAT,TOA,PBAR(2)
C        CLEAR AND INITIALIZE
      CALL CLINT
C
C       READ RECEPTOR COORDINATES
  401 READ(IRD,402,END=403)RX,RY,KPX(9),KPX(10),NROSE
C         RX: COORDINATE OF RECEPTOR
C         RY: COORDINATE OF RECEPTOR
C         KPX(9): OBSERVED P 1 CONCENTRATION AT THIS RECEPTOR IF KNOWN
C         KPX(10): OBSERVED  P 2 CONCENTRATION AT THIS RECEPTOR IF KNOWN
  402 FORMAT(2F8.2,14X,I4,3X,I4,I5)
C        CONVERT COORDINATES TO EMISSION GRID UNITS
      RI=(RX-XG)/RAT+1.
      RJ=(RY-YG)/RAT+1.
      IF(NROSE.GE.1) IPG=IPG+6
      IPG=IPG+1
C        START NEW PAGE IF LINE COUNT GE 50
      IF(IPG.LT.50) GOTO499
      IPG=0
      WRITE(IWR,444)IVER,IRUN
  444 FORMAT('1',40X,'CDM VERSION',I6,',  RUN',I6)
      WRITE(IWR,445)
  445 FORMAT(' ',40X,'(MICROGRAMS PER CUBIC METER)')
      WRITE(IWR,410)
  410 FORMAT(' ',30X,'AREA',15X,'POINT',15X,'TOTAL',13X,'CALIBRATED',
     *11X,'OBSERVED')
      WRITE(IWR,409)
  409 FORMAT(' ',5X,'COORDINATES',3X,5(7X,'P 1',6X,' P 2'))
  499 K=1
C         K: PROGRESSES 1 THRU 16 CONTROLLING SECTOR (DIRECTION)
      DO500I=1,2
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      ABAR(I)=0.                                                        00000410
      PBAR(I)=0.                                                        00000420
      AROSE(K,I)=0.                                                     00000430
  500 PROSE(K,I)=0.                                                     00000440
      IF(IAS.LT.1) GOTO666                                              00000450
C        DETERMINE MAX. DISTANCE FROM RECEPTOR ACROSS AREA GRID (MX)    00000460
      DX(1)=(IX-0.5)-RI                                                 00000470
      DX(2)=(IXX+0.5)-RI                                                00000480
      DX(3)=DX(2)                                                       00000490
      DX(4)=DX(1)                                                       00000500
      DY(1)=(IY-0.5)-RJ                                                 00000510
      DY(2)=DY(1)                                                       00000520
      DY(3)=(IYY+0.5)-RJ                                                00000530
      DY(4)=DY(3)                                                       00000540
      TX=(DX(1)*DX(1)+DY(1)*DY(1))**0.5                                 00000550
      TN=TX                                                             00000560
      TM=(DX(2)*DX(2)+DY(1)*DY(1))**0.5                                 00000570
      IF(TM.GT.TX) TX=TM                                                00000580
      IF(TM.LT.TN) TN=TM                                                00000590
      TM=(DX(2)*DX(2)+DY(3)*DY(3))**0.5                                 00000600
      IF(TM.GT.TX) TX=TM                                                00000610
      IF(TM.LT.TN) TN=TM                                                00000620
      TM=(DX(1)*DX(1)+DY(3)*DY(3))**0.5                                 00000630
      IF(TM.GT.TX) TX=TM                                                00000640
      IF(TM.LT.TN) TN=TM                                                00000650
      MX=TX/DR                                                          00000660
C        TEST IF RECEPTOR WITHIN AREA SOURCE                            00000670
      IF(RI+0.5.LT.IX.OR.RI-0.5.GT.IXX) GOTO4                           00000680
      IF(RJ+0.5.LT.IY.OR.RJ-0.5.GT.IYY) GOTO4                           00000690
      IB=1                                                              00000700
      MN=1                                                              00000710
      GOTO61                                                            00000720
    4 IB=2                                                              00000730
C        DETERMINE MINIMUM DISTANCE FROM RECEPTOR TO AREA SOURCES       00000740
      TMN=TN/DR                                                         00000750
      TXI=0.                                                            00000760
      TNI=400.                                                          00000770
      DO17I=1,4                                                         00000780
      IF(DX(I))5,6,7                                                    00000790
    5 IF(DY(I).EQ.0.) GOTO9                                             00000800
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      TA(I)=ATAN(DY(I)/DX(I))*RAD+180.                                   00000810
      GOTO16                                                             00000820
    9 TA(I)=180.                                                         00000830
      GOTO16                                                             00000840
    6 IF(DY(I))10,11,12                                                  00000850
   10 TA(I)=270.                                                         00000860
      GOTO16                                                             00000870
   11 TA(I)=0.                                                           00000880
      GOTO16                                                             00000890
   12 TA(I)=90.                                                          00000900
      GOTO16                                                             00000910
    7 IF(DY(I))13,14,15                                                  00000920
   13 TA(I)=ATAN(DY(I)/DX(I))*RAD+360.                                   00000930
      GOTO16                                                             00000940
   14 TA(I)=360.                                                         00000950
      GOTO16                                                             00000960
   15 TA(I)=ATAN(DY(I)/DX(I))*RAD                                        00000970
   16 IF(TA(I).GT.TXI) TXI=TA(I)                                         00000980
      IF(TA(I).LT.TNI) TNI=TA(I)                                         00000990
   17 CONTINUE                                                           00001000
      TDIF=TXI-TNI                                                       00001010
   70 DO96I=1,4                                                          00001020
   96 A(I)=TA(I)                                                         00001030
      TX=TXI                                                             00001040
      TN=TNI                                                             00001050
      IF(TDIF.GT.180.) GOTO29                                            00001060
      TM=90.-TK(K)                                                       00001070
      IF(TM.LT.0.) TM=TM+360.                                            00001080
   27 IF(TM.GE.TN-11.25) GOTO28                                          00001090
      IF(TM.GE.11.25) GOTO666                                            00001100
      TM=TM+360.                                                         00001110
   28 IF(TM-(TX+11.25))40,40,666                                         00001120
   29 TM=180.-TK(K)                                                      00001130
      IF(TM.LT.0.) TM=TM+360.                                            00001140
   30 TX=0.                                                              00001150
      TN=400.                                                            00001160
      DO36I=1,4                                                          00001170
      A(I)=A(I)+90.                                                      00001180
      IF(A(I).GE.360.) A(I)=A(I)-360.                                    00001190
      IF(A(I).GT.TX) TX=A(I)                                             00001200
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      IF(A(I).LT.TN) TN=A(I)                                            00001210
   36 CONTINUE                                                          00001220
      IF(TX-TN.LE.180.) GOTO27                                          00001230
      TM=270.-TK(K)                                                     00001240
      IF(TM.LT.0.) TM=TM+360.                                           00001250
      GOTO30                                                            00001260
   40 DIF=(TX-TN)/(2.*RAD)                                              00001270
      MN=TMN*COS(DIF)                                                   00001280
C           NEGATE POSSIBLE ERROR IN COSINE FUNCTION.                   00001290
      L=MOD(MN,INC(4))                                                  00001300
      IF(L.LE.0) L=INC(4)                                               00001310
      MN=MN-L                                                           00001320
C        MN ALWAYS EQUALS 1 IF RECEPTOR WITHIN AREA SOURCE GRID         00001330
      IF(MN.LT.1) MN=1                                                  00001340
   61 N=MN                                                              00001350
      CALL CALQ                                                         00001360
      CALL AREA                                                         00001370
C        IF NO POINT SOURCES, GO TO NEXT SECTOR                         00001380
  666 IF(IPS.LE.0) GOTO408                                              00001390
      CALL POINT                                                        00001400
  408 IF(K.GE.16) GOTO452                                               00001410
      K=K+1                                                             00001420
C        K LOOPS THRU 16 SECTORS                                        00001430
      DO503I=1,2                                                        00001440
      AROSE(K,I)=0.                                                     00001450
  503 PROSE(K,I)=0.                                                     00001460
C        IF NO AREA SOURCES, CHECK POINT SOURCES                        00001470
      IF(IAS.LT.1) GOTO666                                              00001480
C        BRANCH TO 61 OR 70 DEPENDS ON WHETHER RECEPTOR IS INSIDE AREA G00001490
      GOTO(61,70),IB                                                    00001500
C        PRINT AND PUNCH OUTPUT                                         00001510
  452 DO505I=1,2                                                        00001520
      TCON(I)=PBAR(I)+ABAR(I)                                           00001530
  505 CCON(I)=CA(I)+CB(I)*TCON(I)                                       00001540
C         TCON: TOTAL CONCENTRATION                                     00001550
C         CCON: CALIBRATED CONCENTRATION                                00001560
      WRITE(IWR,412)RX,RY,ABAR,PBAR,TCON,CCON,KPX(9),KPX(10)            00001570
  412 FORMAT(' ',F9.2,F10.2,8F10.0,2I10)                                00001580
C           ABAR: CONTRIBUTION FROM AREA SOURCES                        00001590
C           PBAR: CONTRIBUTION FROM POINT SOURCES                       00001600
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      PUX=(RX-XGG)/RATG+1.                                                  00001610
C        PUX: X COORDINATE OF PLOTTING GRID                                 00001620
      PUY=(RY-YGG)/RATG+1.                                                  00001630
C        PUY: Y COORDINATE OF PLOTTING GRID                                 00001640
C        KPX: CARD OUTPUT VECTOR                                            00001650
      KPX(1)=ABAR(1)+0.5                                                    00001660
      KPX(2)=ABAR(2)+0.5                                                    00001670
      KPX(3)=PBAR(1)+0.5                                                    00001680
      KPX(4)=PBAR(2)+0.5                                                    00001690
      KPX(5)=TCON(1)+0.5                                                    00001700
      KPX(6)=TCON(2)+0.5                                                    00001710
      KPX(7)=CCON(1)+0.5                                                    00001720
      KPX(8)=CCON(2)+0.5                                                    00001730
      WRITE(IPU,405)PUX,PUY,(KPX(L),L=1,10),RX,RY,IRUN                      00001740
  405 FORMAT(F8.2,F6.2,10I4,2F10.2,I5,'I')                                  00001750
      IF(NROSE.LT.1) GOTO401                                                00001760
      KPX(17)=RX*100.                                                       00001770
      KPX(18)=RY*100.                                                       00001780
      WRITE(IWR,461)                                                        00001790
  461 FORMAT(' AREA  ROSES')                                                00001800
      DO463J=1,2                                                            00001810
      DO462I=1,16                                                           00001820
  462 KPX(I)=AROSE(I,J)+0.5                                                 00001830
      WRITE(IWR,467)AROS(J),KPX                                             00001840
  467 FORMAT(' ',6X,A4,18I5)                                                00001850
  463 WRITE(IPU,464)AROS(J),KPX                                             00001860
      WRITE(IWR,468)                                                        00001870
  468 FORMAT(' POINT ROSES')                                                00001880
      DO466L=1,2                                                            00001890
      DO465K=1,16                                                           00001900
  465 KPX(K)=PROSE(K,L)+0.5                                                 00001910
      WRITE(IWR,467)PROS(L),KPX                                             00001920
  466 WRITE(IPU,464)PROS(L),KPX                                             00001930
  464 FORMAT(A4,16I4,2I6)                                                   00001940
      GOTO401                                                               00001950
  403 CALL EXIT                                                             00001960
      END                                                                   00001970
                                   CALQ
      SUBROUTINE CALQ                                                       00001980
      DIMENSION C(3)                                                        00001990
      COMMON /C1/ K,MX,MN,HT,F(6,6,16),G(6,5),U(6),RI,RJ,INC(4),DELR        00002000
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      COMMON /C2/ UE(6),YD,YN,TMN,HMIN,DINT,YCON,TA(4),IPG,XG,YG,IRD     00002010
      COMMON /C3/ RATG,IRUN,CA(2),CB(2),TK(16),AROS(2),PROS(2),TANG      00002020
      COMMON /C4/ DECAY(2),ICA(6),ICP(6),H(6),HX(6),GB(2),NQ,IVER,IWR    00002030
      COMMON /C5/ Q(100,4),GA(2),IAD(4,5),XGG,YGG,IAS,TDA,TDB,TDC,IPU    00002040
      COMMON /QCOM/ N,DR,IX,IY,TT(16,21),KTC,IXX,IYY,RAD,Z(50,50,3),TD  00002050
C         CALCULATE SECTOR AREA SOURCE VECTOR Q(NQ,I)                    00002060
C             N = INDEX OF RADIAL ARC                                    00002070
C             I = 1: P 1 EMISSION RATE                                   00002080
C             I = 2:  P 2 EMISSION RATE                                  00002090
C             I = 3: AREA STACK HEIGHT                                   00002100
      NQ=0                                                               00002110
  700 NQ=NQ+1                                                            00002120
      DO701I=1,3                                                         00002130
  701 Q(NQ,I)=0.                                                         00002140
      Q(NQ,4)=(N-1)*DELR                                                 00002150
      R=(N-1)*DR                                                         00002160
C         R: RADIAL UPWIND DISTANCE                                      00002170
      KT=(N-1)*DELR/2500.+1.                                             00002180
C         KT: CONTROLS INCREMENT TO NEXT ARC                             00002190
      IF(KT.GT.4) KT=4                                                   00002200
C         KTC: CONTROLS NUMBER OF POINTS ALONG ARC (DINT+1)              00002210
      HN=0.                                                              00002220
      DO90LL=1,KTC                                                       00002230
C         DETERMINE WHICH AREA SOURCE THE POINT FALLS ON.  IF ON THE LINE00002240
C             TWO ARE AVERAGED.  IF ON AN INTERSECTION, FOUR ARE AVERAGED 00002250
      T=TT(K,LL)                                                         00002260
      TI=RI+R*COS(T)                                                     00002270
      TJ=RJ+R*SIN(T)                                                     00002280
      IF(TI.LT.TDA.OR.TI.GT.TDB) GOTO90                                  00002290
      IF(TJ.LT.TDA.OR.TJ.GT.TDC) GOTO90                                  00002300
      I=TI                                                               00002310
      J=TJ                                                               00002320
      IF(I.LT.1) I=1                                                     00002330
      IF(J.LT.1) J=1                                                     00002340
      D=TI-I                                                             00002350
      IF(ABS(D-0.5).LE.TD) GOTO78                                        00002360
      IF(D-0.5)82,78,86                                                  00002370
   78 D=TJ-J                                                             00002380
      IF(ABS(D-0.5).LE.TD) GOTO79                                        00002390
      IF(D-0.5)80,79,81                                                  00002400
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
   79 IA=1                                                              00002410
      JA=5                                                              00002420
      GOTO101                                                           00002430
   80 IA=2                                                              00002440
      JA=3                                                              00002450
      GOTO101                                                           00002460
   81 IA=2                                                              00002470
      JA=4                                                              00002480
      GOTO101                                                           00002490
   82 D=TJ-J                                                            00002500
      IF(ABS(D-0.5).LE.TD) GOTO83                                       00002510
      IF(D-0.5)84,83,85                                                 00002520
   83 IA=3                                                              00002530
      JA=2                                                              00002540
      GOTO101                                                           00002550
   84 IA=3                                                              00002560
      JA=3                                                              00002570
      GOTO101                                                           00002580
   85 IA=3                                                              00002590
      JA=4                                                              00002600
      GOTO101                                                           00002610
   86 D=TJ-J                                                            00002620
      IF(ABS(D-0.5).LE.TD) GOTO87                                       00002630
      IF(D-0.5)88,87,89                                                 00002640
   87 IA=4                                                              00002650
      JA=2                                                              00002660
      GOTO101                                                           00002670
   88 IA=4                                                              00002680
      JA=3                                                              00002690
      GOTO101                                                           00002700
   89 IA=4                                                              00002710
      JA=4                                                              00002720
  101 CN=0.                                                             00002730
      IF(I.EQ.IXX) IA=3                                                 00002740
      IF(J.EQ.IYY) JA=3                                                 00002750
      DO808LD=1,3                                                       00002760
  808 C(LD)=0.                                                          00002770
      DO802IR=1,4                                                       00002780
      IV=I+IAD(IR,IA)                                                   00002790
      JV=J+IAD(IR,JA)                                                   00002800
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      DO801L=1,2                                                        00002810
  801 C(L)=C(L)+Z(IV,JV,L)                                              00002820
      IF(Z(IV,JV,3).LE.0.1) GOTO802                                     00002830
      CN=CN+1.                                                          00002840
      C(3)=C(3)+Z(IV,JV,3)                                              00002850
  802 CONTINUE                                                          00002860
      C(1)=C(1)/4.                                                      00002870
      C(2)=C(2)/4.                                                      00002880
      IF(CN.GT.0.5) GOTO803                                             00002890
      C(3)=1.                                                           00002900
      GOTO804                                                           00002910
  803 C(3)=C(3)/CN                                                      00002920
  804 IF(R.GT.0.) GOTO103                                               00002930
      DO201LA=1,3                                                       00002940
  201 Q(NQ,LA)=C(LA)                                                    00002950
      GOTO102                                                           00002960
  103 IF(LL.NE.1.AND.LL.NE.KTC) GOTO104                                 00002970
C        TRAPEZOIDAL INTEGRATION APPLIED                                00002980
      DO203LB=1,2                                                       00002990
  203 C(LB)=C(LB)*0.5                                                   00003000
  104 DO204LC=1,2                                                       00003010
  204 Q(NQ,LC)=Q(NQ,LC)+C(LC)                                           00003020
      IF(C(1)+C(2).LE.0.) GOTO90                                        00003030
      Q(NQ,3)=Q(NQ,3)+C(3)                                              00003040
   99 HN=HN+1.                                                          00003050
   90 CONTINUE                                                          00003060
      DO202LD=1,2                                                       00003070
  202 Q(NQ,LD)=Q(NQ,LD)/DINT                                            00003080
      IF(HN.GT.0.5) GOTO105                                             00003090
      Q(NQ,3)=1.                                                        00003100
      GOTO102                                                           00003110
  105 Q(NQ,3)=Q(NQ,3)/HN                                                00003120
  102 N=N+INC(KT)                                                       00003130
      IF(N.LE.MX+1) GOTO700                                             00003140
C        IF NEXT ARC IS BEYOND AREA GRID, RETURN                        00003150
      Q(NQ+1,4)=(N-1)*DELR                                              00003160
      RETURN                                                            00003170
      END                                                               00003180
                                 AREA
      SUBROUTINE AREA                                                   00003190
      DIMENSION C(2)                                                    00003200
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      COMMON /C1/ K,MX,MN,HT,F(6,6,16),G(6,5),U(6),HI,HJ,INC(4),DELH    00003210
      COMMON /C2/ UE(6),YD,YN,TMN,HMIN,DINT,YCON,TA(4),IPG,XG,YG,IRU    00003220
      COMMON /C3/ HATG,IRUN,CA(2),CB(2),TK(16),AHOS(2),PHOS(2),TANG     00003230
      COMMON /C4/ DECAY(2),ICA(6),ICP(6),M(6),MX(6),GB(2),NO,IVER,IWH   00003240
      COMMON /C5/ Q(100,4),GA(2),IAD(4,5),XGG,YGG,IAS,TDA,TDB,TDC,IPU   00003250
      COMMON /ACOM/ PI,SZA(6),AHAR(2),AHOSE(16,2),AS(6)                 00003260
      Y=YD                                                              00003270
C        CALCULATE SECTOR CONCENTRATION FROM AREA SOURCE VECTOR (Q)     00003280
      DO338IS=1,6                                                       00003290
C        IS: CONTROLS STABILITY CLASS                                   00003300
      IF(IS.EQ.5) Y=YN                                                  00003310
      IC=ICA(IS)                                                        00003320
      DO338IU=1,6                                                       00003330
C        IU: CONTOLS WIND SPEED CLASS                                   00003340
C        IF FREQUENCY IS ZERO, SKIP                                     00003350
      IF(F(IS,IU,K).LE.0.) GOTO338                                      00003360
      C(1)=0.                                                           00003370
      C(2)=0.                                                           00003380
      IW=1                                                              00003390
      DVLRI=Q(2,4)-Q(1,4)                                               00003400
  701 W=Q(IW,4)                                                         00003410
      DVLW=DVLRI                                                        00003420
      DVLRI=Q(IW+1,4)-W                                                 00003430
      WZ=(Q(IW,3)*0.1)**UE(IS)                                          00003440
      WS=U(IU)*WZ                                                       00003450
      DO801JA=1,2                                                       00003460
      DF=WS*GA(JA)                                                      00003470
  801 DECAY(JA)=EXP(W/DF)                                               00003480
      WAS=W+AS(IS)                                                      00003490
      IF(WAS-5000.)311,313,310                                          00003500
  310 IZ=1                                                              00003510
      GOTO327                                                           00003520
  311 IF(WAS.GE.500.) GOTO313                                           00003530
      IZ=3                                                              00003540
      GOTO327                                                           00003550
  313 IZ=2                                                              00003560
  327 SZ=G(IZ,IC)*WAS**G(IZ+3,IC)                                       00003570
      IF(SZ.LE.0.) GOTO344                                              00003580
      IF(SZ.GE.HA(IS)) GOTO317                                          00003590
      STKZ=Q(IW,3)*Q(IW,3)                                              00003600
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV. LEVEL G

```
      SB=-0.5*STK2/(SZ*SZ)                                             00003610
      S=PI*EXP(SB)/(SZ*WS)                                             00003620
      GOTO319                                                          00003630
  317 S=1./(WS*H(IS))                                                  00003640
C         LID HAS BEEN REACHED                                         00003650
      IRI=IR                                                           00003660
  702 R=Q(IRI,4)                                                       00003670
      DVLR=DVLRI                                                       00003680
      DVLRI=Q(IRI+1,4)-R                                               00003690
      WZ=(Q(IRI,3)*0.1)**UE(IS)                                        00003700
      WS=U(IU)*WZ                                                      00003710
      DO802JB=1,2                                                      00003720
      DF=WS*GA(JB)                                                     00003730
  802 DECAY(JB)=EXP(R/DF)                                              00003740
      IF(IRI.EQ.1.OR.IRI.EQ.NQ) GOTO320                                00003750
      DO465JC=1,2                                                      00003760
  465 C(JC)=C(JC)+(Q(IRI,JC)*S*(DVLR+DVLRI))/DECAY(JC)                 00003770
      GOTO366                                                          00003780
C         TRAPEZOIDAL INTEGRATION APPLIED                              00003790
  320 DO445JF=1,2                                                      00003800
  445 C(JF)=C(JF)+(Q(IRI,JF)*S*DVLR)/DECAY(JF)                         00003810
  366 IRI=IRI+1                                                        00003820
C         LOOPS TO RHO(MAX)                                            00003830
      IF(IRI.LE.NQ) GOTO702                                            00003840
      GOTO347                                                          00003850
  319 IF(IR.EQ.1.OR.IR.EQ.NQ) GOTO323                                  00003860
C         LID HAS NOT BEEN REACHED                                     00003870
C         TRAPEZOIDAL INTEGRATION APPLIED                              00003880
      DO462JI=1,2                                                      00003890
  462 C(JI)=C(JI)+(Q(IR,JI)*S*(DVLR+DVLRI))/DECAY(JI)                  00003900
      GOTO346                                                          00003910
C         TRAPEZOIDAL INTEGRATION APPLIED                              00003920
  323 DO423JK=1,2                                                      00003930
  423 C(JK)=C(JK)+(Q(IR,JK)*S*DVLR)/DECAY(JK)                          00003940
  346 IR=IR+1                                                          00003950
C         LOOPS TO RHO(MAX)                                            00003960
      IF(IR.LE.NQ) GOTO701                                             00003970
  347 X=Y*YCON*F(IS,IU,K)                                              00003980
      DO447JL=1,2                                                      00003990
      AROSE(K,JL)=AROSE(K,JL)+C(JL)*X                                  00004000
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
  447 ABAR(JL)=ABAR(JL)+C(JL)*X                                         00004010
  338 CONTINUE                                                          00004020
      RETURN                                                            00004030
      END                                                               00004040
                                 POINT
      SUBROUTINE POINT                                                  00004050
      DIMENSION S(2)                                                    00004060
      COMMON /C1/ K,MX,MN,HT,F(6,6,16),G(6,5),U(6),RI,RJ,INC(4),DELR    00004070
      COMMON /C2/ UE(6),YD,YN,TMN,HMIN,DINT,YCON,TA(4),IPG,XG,YG,IRD    00004080
      COMMON /C3/ RATG,IRUN,CA(2),CB(2),TK(16),AROS(2),PROS(2),TANG     00004090
      COMMON /C4/ DECAY(2),ICA(6),ICP(6),H(6),HX(6),GB(2),NQ,IVER,IWR   00004100
      COMMON /C5/ Q(100,4),GA(2),IAD(4,5),XGG,YGG,IAS,TDA,TDB,TDC,IPU   00004110
      COMMON /PCOM/ PH(200),PR(200),PS(200,4),PX(200),PY(200),FB(200),  00004120
     *XX(200),DHF(200),WA(16),WB(16),PROSE(16,2),CV,IPS,RAT,TOA,PBAR(2) 00004130
C        CALCULATE SECTOR CONCENTRATION FROM POINT SOURCES              00004140
C          IP LOOPS TO IPS (NUMBER OF POINT SOURCES)                    00004150
      IP=1                                                              00004160
C          FINDS UPWIND (XP) AND CROSSWIND (YP) DISTANCES FROM RECEPTOR 00004170
C             TO SOURCE                                                 00004180
  667 VX=PX(IP)-RI                                                      00004190
      VY=PY(IP)-RJ                                                      00004200
      XP=(VY*WA(K)+VX*WB(K))*RAT*CV                                     00004210
      IF(XP.LE.0.) GOTO659                                              00004220
      YP=ABS((VY*WB(K)-VX*WA(K))*RAT*CV)                                00004230
      TM=XP*0.19891                                                     00004240
C          IF SOURCE MAKES NO CONTRIBUTION TO RECEPTOR. SKIP TO NEXT    00004250
      IF(YP.GT.TM) GOTO659                                              00004260
      IF(PH(IP).GE.50.) GOTO654                                         00004270
      SZI=50.-PH(IP)                                                    00004280
      IF(SZI.GT.30.) SZI=30.                                            00004290
      GOTO635                                                           00004300
  654 SZI=0.                                                            00004310
  635 Y=YD                                                              00004320
      DO658IS=1,6                                                       00004330
C          IS: CONTROLS STABILITY CLASS                                 00004340
      IF(IS.EQ.5) Y=YN                                                  00004350
      IC=ICP(IS)                                                        00004360
      WZ=(PH(IP)*0.1)**UE(IS)                                           00004370
      IF(SZI.LE.0.) GOTO650                                             00004380
      XS=(SZI/G(1,IC))**(1./G(4,IC))                                    00004390
      IF(XS.GE.5000.) GOTO624                                           00004400
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      XS=(SZI/G(2,IC))**(1./G(5,IC))                                    00004410
      IF(XS.GE.500.) GOTO624                                            00004420
      XS=(SZI/G(3,IC))**(1./G(6,IC))                                    00004430
      GOTO624                                                           00004440
  650 XS=0.                                                             00004450
  624 DIST=XP+XS                                                        00004460
      IF(DIST-5000.)641,643,640                                         00004470
  640 IZ=1                                                              00004480
      GOTO644                                                           00004490
  641 IF(DIST.GE.500.) GOTO643                                          00004500
      IZ=3                                                              00004510
      GOTO644                                                           00004520
  643 IZ=2                                                              00004530
  644 SZ=G(IZ,IC)*DIST**G(IZ+3,IC)                                      00004540
      IF(SZ.LE.0.) GOTO658                                              00004550
      DO658IU=1,6                                                       00004560
C         IU: CONTOLS WIND SPEED CLASS                                  00004570
C         IF FREQUENCY IS ZERO, SKIP                                    00004580
      IF(F(IS,IU,K).LE.0.) GOTO658                                      00004590
      WS=U(IU)*WZ                                                       00004600
      DO744JA=1,2                                                       00004610
      DF=WS*GA(JA)                                                      00004620
  744 DECAY(JA)=EXP(XP/DF)                                              00004630
      IF(PR(IP).LE.0.) GOTO637                                          00004640
C              HOLLANDS EQN.                                            00004650
      DH=PR(IP)/WS                                                      00004660
      DH=DH*(1.4-0.1*IC)                                                00004670
      GOTO638                                                           00004680
C             BRIGGS PLUME RISE   (1970)                                00004690
  637 XSX=XP/XX(IP)                                                     00004700
      IF(XSX.GT.3.5) GOTO608                                            00004710
      DH=FB(IP)/WS*XP**0.6667                                           00004720
      GOTO638                                                           00004730
  608 DH=DHF(IP)/WS                                                     00004740
  638 PHDH=PH(IP)+DH                                                    00004750
      IF(PHDH.GT.H(IS)) GOTO658                                         00004760
      PHDH=PHDH*PHDH                                                    00004770
      IF(SZ.GE.HX(IS)) GOTO614                                          00004780
      B=-0.5*(PHDH/(SZ*SZ))                                             00004790
      IF(ABS(B).GT.60.) GOTO658                                         00004800
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      WW=WS*XP*SZ
      S(1)=PS(IP,1)/WW
      S(2)=PS(IP,2)/WW
      WW=EXP(B)
      S(1)=S(1)*WW
      S(2)=S(2)*WW
      GOTO615
  614 WW=WS*XP*H(IS)
      S(1)=PS(IP,3)/WW
      S(2)=PS(IP,4)/WW
  615 B=Y*YCON*F(IS,IU,K)
      DO715JB=1,2
      X=S(JB)*B/DECAY(JB)
      PROSE(K,JB)=PROSE(K,JB)+X
  715 PBAR(JB)=PBAR(JB)+X
  658 CONTINUE
  659 IP=IP+1
      IF(IP.LE.IPS) GOTO667
C        LOOPS UNTIL ALL POINT SOURCES EVALUATED
      RETURN
      END
                               CLINT

      SUBROUTINE CLINT
      COMMON /C1/ K,MX,MN,HT,F(6,6,16),G(6,5),U(6),RI,RJ,INC(4),DELR
      COMMON /C2/ UE(6),YD,YN,TMN,HMIN,DINT,YCON,TA(4),IPG,XG,YG,IRD
      COMMON /C3/ RATG,IRUN,CA(2),CB(2),TK(16),AROS(2),PROS(2),TANG
      COMMON /C4/ DECAY(2),ICA(6),ICP(6),H(6),HX(6),GB(2),NQ,IVER,IWR
      COMMON /C5/ Q(100,4),GA(2),IAD(4,5),XGG,YGG,IAS,TDA,TDB,TDC,IPU
      COMMON /QCOM/ N,DR,IX,IY,TT(16,21),KTC,IXX,IYY,RAD,Z(50,50,3),TD
      COMMON /ACOM/ PI,SZA(6),ABAR(2),AROSE(16,2),XS(6)
      COMMON /PCOM/ PH(200),PR(200),PS(200,4),PX(200),PY(200),FB(200),
     *XX(200),DHF(200),WA(16),WB(16),PROSE(16,2),CV,IPS,RAT,TOA,PBAR(2)
C        SUBROUTINE CLEARS AND INITIALIZES.
      DO533I=1,50
      DO533J=1,50
C        EFFECTIVE STACK HEIGHT MUST BE GE 1.
      Z(I,J,3)=1.
      DO533K=1,2
  533 Z(I,J,K)=0.
C        U(N): CENTER SPEED OF SIX WIND SPEED CLASSES
      TK(1)=0.
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      DO544I=2,16                                                       00005210
  544 TK(I)=TK(I-1)+22.5                                                00005220
C        UE(N): EXPONENTIAL OF WIND PROFILE.  0.001 = NO PROFILE.       00005230
C           N = STABILITY CLASS                                         00005240
      READ(5,545)AROS,PROS,IRUN,NLIST,IRD,IWR,IPU,CA,CB                 00005250
C        AROS,PROS: OUTPUT CARD IDENTIFIERS                             00005260
C        IRUN: IDENTIFICATION NUMBER                                    00005270
C        NLIST: INPUT LIST OPTION.  NLIST LE ZERO PRODUCES LIST         00005280
C        CA,CB: INTERCEPT, SLOPE OF CALIBRATION                         00005290
  545 FORMAT(4A4,5I5,4F9.0)                                             00005300
C       INPUT MODEL PARAMETERS                                          00005310
      READ(5,504)DELR,RAT,CV,HT,HMIN,XG,YG,XGG,YGG,RATG,TOA,TXX         00005320
C        DELR: INTEGRATION INCREMENT (RADIAL DISTANCE (M))              00005330
C        RAT: RATIO, EMISSION GRID TO MAP GRID                          00005340
C        CV: CONVERSION. CV*RAT = EMISSION GRID INTERVAL (M)            00005350
C        HT: AVERAGE AFTERNOON MIXING HEIGHT (M)                        00005360
C        HMIN: NOCTURNAL MIXING HEIGHT (M)                              00005370
C        XG: MAP COORDINATE X, SOUTHWEST CORNER OF EMISSION GRID        00005380
C        YG: MAP COORDINATE Y, SOUTHWEST CORNER OF EMISSION GRID        00005400
C        XGG: MAP COORDINATE X, SOUTHWEST CORNER OF PLOTTING GRID       00005420
C        YGG: MAP COORDINATF Y, SOUTHWEST CORNER OF PLOTTING GRID       00005440
C        RATG: RATIO, EMISSION GRID TO MAP GRID                         00005460
C        TOA: MEAN AMBIENT TEMPERATURE (C)                              00005470
C        TXX: WIDTH OF A BASIC AREA SOURCE SQUARE (M)                   00005480
  504 FORMAT(12F6.0)                                                    00005520
      READ(5,504)DINT,YD,YN,SZA,GB                                      00005530
C        DINT: NUMBER OF SEGMENTS DESIRED IN 22.5 DEG. SECTORS..        00005540
C           RANGE 2 TO 20 INCLUSIVE.                                    00005550
C        YD: RATIO, AVG. DAYTIME EMISSION / 24-HR EMISSION              00005560
C        YN: RATIO, AVG. NIGHTTIME EMISSION / 24-HR EMISSION            00005570
C        SZA(N): INITIAL SIGMA Z FOR AREA SOURCES (M)                   00005580
C           N = STABILITY CLASS                                         00005590
C        GB(N): DECAY RATE HALF LIFE                                    00005600
```

Table C-1 (continued). FORTRAN STATEMENTS. FORTRAN IV. LEVEL G

```
C         N=1:  P 1.  N=2:  P 2                                        00005610
C       INPUT RELATIVE FREQUENCY TABLE OF STABILITY.WIND SPEED. AND DIRE00005620
      DO513I=1.6                                                        00005630
      DO513K=1.16                                                       00005640
  513 READ(IRD.514)(F(I.J.K).J=1.6)                                     00005650
C         F(I.J.K): JOINT FREQUENCY FUNCTION...                         00005660
C            I = STABILITY CLASS                                        00005670
C            J = WIND SPEED CLASS                                       00005680
C            K = WIND DIRECTION                                         00005690
  514 FORMAT(9X.6F9.0)                                                  00005700
      TOA=TOA+273.16                                                    00005710
      DR=DELR/(CV*RAT)                                                  00005720
      KTC=DINT+1.                                                       00005730
      THETA=22.5/DINT                                                   00005740
      DO519I=1.16                                                       00005750
      B=TK(I)/RAD                                                       00005760
      WB(I)=SIN(B)                                                      00005770
      WA(I)=COS(B)                                                      00005780
      DO519J=1.KTC                                                      00005790
      X=TANG-TK(I)+(J-1)*THETA                                          00005800
      IF(X.LT.0.) X=X+360.                                              00005810
  519 TT(I.J)=X/RAD                                                     00005820
C         DEFINE HALF LIFE FOR P 1 AND  P 2                             00005830
      GA(1)=GB(1)*3600./0.693                                           00005840
      GA(2)=GB(2)*3600./0.693                                           00005850
      H(1)=HT*1.5                                                       00005860
      H(2)=HT                                                           00005870
      H(3)=HT                                                           00005880
      H(4)=HT                                                           00005890
      H(5)=(HT+HMIN)*0.5                                                00005900
      H(6)=HMIN                                                         00005910
      DO114JA=1.6                                                       00005920
      JB=ICA(JA)                                                        00005930
      HX(JA)=0.8*H(JA)                                                  00005940
      SA=SZA(JA)                                                        00005950
      IF(SA.GT.0.) GOTO110                                              00005960
      S=0.                                                              00005970
      GOTO114                                                           00005980
  110 S=(SA/G(1.JB))**(1./G(4.JB))                                      00005990
      IF(S.GE.5000.) GOTO114                                            00006000
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      S=(SA/G(2,JB))**(1./G(5,JB))                                      00006010
      IF(S.GE.500.) GOTO114                                             00006020
      S=(SA/G(3,JB))**(1./G(6,JB))                                      00006030
  114 XS(JA)=S                                                          00006040
      IF(NLIST.GT.0) GOTO501                                            00006050
      WRITE(IWR,800)IVER,IRUN                                           00006060
  800 FORMAT('1',40X,'CDM VERSION',I6,',  RUN',I6)                      00006070
      WRITE(IWR,801)                                                    00006080
  801 FORMAT('0THE CENTRAL WIND SPEEDS OF THE SIX WIND SPEED CLASSES (U)00006090
     *:')                                                               00006100
      WRITE(IWR,802)U                                                   00006110
  802 FORMAT(' ',6E20.6)                                                00006120
      WRITE(IWR,803)                                                    00006130
  803 FORMAT('0THE EXPONENTIAL OF THE VERTICAL WIND PROFILE BY STABILITY00006140
     * CLASS (UE):')                                                    00006150
      WRITE(IWR,802)UE                                                  00006160
      WRITE(IWR,804)                                                    00006170
  804 FORMAT('0THE INITIAL SIGMA Z FOR AREA SOURCES BY STABILITY CLASS (00006180
     *SZA):')                                                           00006190
      WRITE(IWR,802)SZA                                                 00006200
      WRITE(IWR,805)                                                    00006210
  805 FORMAT('0THE CLIMATOLOGICAL MEAN NOCTURNAL AND AFTERNOON MIXING HE00006220
     *IGHTS (HMIN,HT):')                                                00006230
      WRITE(IWR,802)HMIN,HT                                             00006240
      WRITE(IWR,806)                                                    00006250
  806 FORMAT('0THE DAY AND NIGHT EMISSION WEIGHT FACTORS (YD,YN):')     00006260
      WRITE(IWR,802)YD,YN                                               00006270
      WRITE(IWR,807)                                                    00006280
  807 FORMAT('0THE X-MIN AND Y-MIN OF THE AREA EMISSION INVENTORY GRID (00006290
     *XG,YG):')                                                         00006300
      WRITE(IWR,802)XG,YG                                               00006310
      WRITE(IWR,808)                                                    00006320
  808 FORMAT('0THE WIDTH OF A BASIC AREA SOURCE SQUARE (TXX):')         00006330
      WRITE(IWR,802)TXX                                                 00006340
      WRITE(IWR,809)                                                    00006350
  809 FORMAT('0THE NUMBER OF SUB-SECTORS CONSIDERED IN A 22.5 DEGREE SEC00006360
     *TOR, AND ANGULAR WIDTH OF A SUB-SECTOR (DINT,THETA):')            00006370
      WRITE(IWR,802)DINT,THETA                                          00006380
      WRITE(IWR,810)                                                    00006390
  810 FORMAT('0THE INITIAL RADIAL INCREMENT (DELR):')                   00006400
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      WRITE(IWR,802)DELR
      WRITE(IWR,813)
  813 FORMAT('0THE RADIAL INCREMENT FACTORS (INC):')
      WRITE(IWR,814)INC
  814 FORMAT(' ',4I20)
      WRITE(IWR,811)
  811 FORMAT('0THE RATIO OF EMISSION GRID TO MAP GRID (RAT):')
      WRITE(IWR,802)RAT
      WRITE(IWR,812)
  812 FORMAT('0THE GRID CONVERSION FACTOR (CV):')
      WRITE(IWR,802)CV
      WRITE(IWR,815)
  815 FORMAT('0THE AMBIENT AIR TEMPERATURE (TOA):')
      WRITE(IWR,802)TOA
      WRITE(IWR,816)
  816 FORMAT('0THE DECAY RATE HALF LIFE FOR P 1 AND P 2 (GB):')
      WRITE(IWR,802)GB
      WRITE(IWR,817)
  817 FORMAT('0THE SIGMA Z COEFFICIENT TABLE (G):')
      WRITE(IWR,802)G
      DO819L=1,2
      WRITE(IWR,800)IVER,IRUN
      WRITE(IWR,823)(N,N=1,6)
  823 FORMAT(' ',12X,'U',I1,5(18X,'U',I1))
      WRITE(IWR,824)
  824 FORMAT(' SECTOR')
      IB=L*3
      IA=IB-2
      DO819I=IA,IB
      WRITE(IWR,818)I
  818 FORMAT('0',40X,'THE JOINT FREQUENCY FUNCTION FOR STABILITY CLASS',
     *I3,/)
      DO819K=1,16
  819 WRITE(IWR,825)K,(F(I,J,K),J=1,6)
  825 FORMAT(' ',I2,6E20.6)
C        INPUT SOURCE DATA
  501 READ(IRD,502)X,Y,TX,S1,S2,SH,D,VS,T,SA
C        X: COORDINATE (SW CORNER OF GRID CELL IF AREA SOURCE)
C        Y: COORDINATE (SW CORNER OF GRID CELL IF AREA SOURCE)
C        SH: STACK HEIGHT (M)  POINT SOURCE ONLY
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV LEVEL G

```
C           S1: SOURCE EMISSION RATE (P 1 IN GRAMS/SECOND)                      00006810
C           S2: SOURCE EMISSION RATE ( P 2 IN GRAMS/SECOND)                     00006820
C           SA: FOR POINT SOURCES, IF BLANK, BRIGGS FORMULA USED, IF NOT        00006830
C              BLANK, SH*WIND SPEED IS USED.                                    00006840
C           TX:  WIDTH OF THIS CELL (M), MUST BE ZERO ON POINT SOURCE           00006850
C           D: STACK DIAMETER (M)                                               00006860
C           T: STACK GAS TEMPERATURE (C)                                        00006870
C           VS: STACK GAS EXIT VELOCITY (M/S)                                   00006880
  502 FORMAT(F6.0,2F7.0,2F8.0,F7.0,F5.0,2F7.0,F5.0)                             00006890
C          TEST END OF SOURCE DATA (BLANK CARD)                                 00006900
      IF(S1+S2.LE.0.) GOTO900                                                   00006910
      IF(NLIST.GT.0) GOTO888                                                    00006920
      IF(IPG.LT.50) GOTO899                                                     00006930
      IPG=0                                                                     00006940
      WRITE(IWR,800)IVER,IRUN                                                   00006950
      WRITE(IWR,826)                                                            00006960
  826 FORMAT(' SOURCE INPUT')                                                   00006970
      WRITE(IWR,822)                                                            00006980
  822 FORMAT(' ',9X,'X',12X,'Y',11X,'TX',11X,'S1',11X,'S2',11X,'SH',            00006990
     *12X,'D',11X,'VS',12X,'T',11X,'SA')                                        00007000
  899 IPG=IPG+1                                                                 00007010
      WRITE(IWR,820)X,Y,TX,S1,S2,SH,D,VS,T,SA                                   00007020
  820 FORMAT(' ',10E13.5)                                                       00007030
C           EFFECTIVE STACK HEIGHT MUST BE GE 1.                                00007040
  888 IF(SH.LT.1.) SH=1.                                                        00007050
C          SEPARATE AREA AND POINT SOURCE DATA                                  00007060
      IF(TX.LE.0.) GOTO510                                                      00007070
C          STORE AREA SOURCE DATA                                               00007080
C           MOVE COORDINATE TO CENTER OF GRID CELL                              00007090
      D=TX*0.5/CV                                                               00007100
      X=X+D                                                                     00007110
      Y=Y+D                                                                     00007120
      W=TX/TXX                                                                  00007130
      S=TX*TX                                                                   00007140
      B=S1/S                                                                    00007150
      D=S2/S                                                                    00007160
C          BECAUSE OF THE METHOD OF INTEGRATION, AREA SOURCES ARE               00007170
C          DIVIDED BY TWO AT THIS POINT FOR MORE EFFICIENT EXECUTION            00007180
C          OF SUBROUTINE AREA.                                                  00007190
      B=B*0.5                                                                   00007200
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      D=D*0.5                                                           00007210
      X=(X-XG)/RAT+1.                                                   00007220
      Y=(Y-YG)/RAT+1.                                                   00007230
      IF(W.GT.1.) GOTO531                                               00007240
      M=X                                                               00007250
      N=Y                                                               00007260
      K=M                                                               00007270
      L=N                                                               00007280
      GOTO539                                                           00007290
  531 S=W*0.5                                                           00007300
      K=(X-S)+0.55                                                      00007310
      L=(Y-S)+0.55                                                      00007320
      M=(K+W)-0.45                                                      00007330
      N=(L+W)-0.45                                                      00007340
  539 DO532I=K,M                                                        00007350
      DO532J=L,N                                                        00007360
      Z(I,J,1)=B                                                        00007370
      Z(I,J,2)=D                                                        00007380
  532 Z(I,J,3)=SH                                                       00007390
      IF(M.GT.IXX) IXX=M                                                00007400
      IF(N.GT.IYY) IYY=N                                                00007410
      IAS=IAS+1                                                         00007420
      GOTO501                                                           00007430
  900 IPG=70                                                            00007440
      TDA=0.5-TD                                                        00007450
      TDB=IXX+0.5+TD                                                    00007460
      TDC=IYY+0.5+TD                                                    00007470
      IF(NLIST.LE.0) WRITE(IWR,821)IAS,IPS                              00007480
  821 FORMAT('0',I10,' AREA SOURCES.',I10,' POINT SOURCES.')            00007490
      RETURN                                                            00007500
C       STORE POINT SOURCE DATA                                         00007510
  510 IPS=IPS+1                                                         00007520
      PX(IPS)=(X-XG)/RAT+1.                                             00007530
      PY(IPS)=(Y-YG)/RAT+1.                                             00007540
      PS(IPS,1)=S1*2.03                                                 00007550
      PS(IPS,2)=S2*2.03                                                 00007560
      PS(IPS,3)=S1*2.55                                                 00007570
      PS(IPS,4)=S2*2.55                                                 00007580
      PH(IPS)=SH                                                        00007590
      PR(IPS)=SA                                                        00007600
```

Table C-1 (continued). FORTRAN STATEMENTS, FORTRAN IV, LEVEL G

```
      IF(SA.GT.0.) GOTO501
      D=D*0.5
      T=T+273.16
      S=(T-TOA)/T*9.8*VS*D*D
      IF(S.GT.55.) GOTO606
      XX(IPS)=14.*S**0.625
      GOTO605
  606 XX(IPS)=34.*S**0.4
  605 FB(IPS)=1.6*S**0.3333
      DHF(IPS)=FB(IPS)*(3.5*XX(IPS))**0.6667
      GOTO501
      END
```

BLOCK DATA

```
      BLOCK DATA
      COMMON /C1/ K,MX,MN,HT,F(6,6,16),G(6,5),U(6),RI,RJ,INC(4),DELR
      COMMON /C2/ UE(6),YD,YN,TMN,HMIN,DINT,YCON,TA(4),IPG,XG,YG,IRD
      COMMON /C3/ RATG,IRUN,CA(2),CB(2),TK(16),AROS(2),PROS(2),TANG
      COMMON /C4/ DECAY(2),ICA(6),ICP(6),H(6),HX(6),GB(2),NQ,IVER,IWR
      COMMON /C5/ Q(100,4),GA(2),IAD(4,5),XGG,YGG,IAS,TDA,TDB,TDC,IPU
      COMMON /QCOM/ N,DR,IX,IY,TT(16,21),KTC,IXX,IYY,RAD,Z(50,50,3),TD
      COMMON /ACOM/ PI,SZA(6),ABAR(2),AROSE(16,2),XS(6)
      COMMON /PCOM/ PH(200),PR(200),PS(200,4),PX(200),PY(200),FB(200),
     *XX(200),DHF(200),WA(16),WB(16),PROSE(16,2),CV,IPS,RAT,TOA,PBAR(2)
      DATA G/2*2.539E-4,.0383,2*2.0886,1.2812,2*.04936,.1393,2*1.1137,
     *.9467,.1154,.1014,.112,.9109,.926,.91,.7368,.2591,.0856,.5642,
     *.6869,.865,1.2969,.2527,.0818,.4421,.6341,.8155/
      DATA TANG,U/78.75,1.5,2.45872,4.4704,6.92912,9.61136,12.51712/
      DATA YCON,UE/0.1E7,0.1,0.15,0.2,0.25,0.25,0.3/
      DATA INC,IPG,IPS,IX,IY/1,2,4,4,70,0,1,1/
      DATA IXX,IYY,IAS/1,1,0/, TD/0.1E-3/
      DATA RAD,PI/57.2958,0.797885/
      DATA IAD/0,0,1,1,0,1,0,1,4*0,4*1,0,1,1,0/
      DATA ICA,ICP/1,1,2,3,4,4,1,2,3,3*4/
      DATA IVER/72313/
      END
```

APPENDIX D:

A CLIMATOLOGICAL MODEL FOR MULTIPLE SOURCE URBAN AIR POLLUTION

by

K.L. Calder

On assignment from
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

Division of Meteorology
National Environmental Research Center
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Paper presented at
First Meeting of the NATO/CCMS Panel on Modeling

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Abstract

The paper describes a revised form of an urban air pollution model, originally proposed in 1968 by D.O. Martin and J.A. Tikvart, for estimating long-term average concentration of gaseous pollutant in terms of appropriate point- and area-source emission inventories for the urban area, together with climatological frequency data relating to wind speed, wind direction, atmospheric stability, and mixing depth. The model is also applied to the estimation of three-month average SO_2 concentrations in St. Louis, Missouri, during the winter of 1964-65. Some shortcomings of the present model are identified and discussed.

A CLIMATOLOGICAL MODEL FOR MULTIPLE SOURCE URBAN AIR POLLUTION

(A Revised Form of a Model First Proposed
by D. O. Martin and J. A. Tikvart)

by K. L. Calder

I. INTRODUCTION

A paper by Martin and Tikvart was presented at the annual meeting of the Air Pollution Control Association in June 1968. The paper described a computerized climatological model for urban air pollution from multiple sources. This source-oriented atmospheric diffusion model permits calculation of the long-period seasonal or annual-average pollutant concentration patterns resulting from multiple point or area-distributed stationary sources. The model input comprises a detailed specification of the magnitude and distribution of pollutant emissions and of the frequency of occurrence of various meteorological conditions during the time-period of concern. The output provides a quantitative estimate of the spatial distribution of urban air quality averaged over the time period considered.

The fundamental physical basis for the model is the assumption that the steady-state spatial concentration distribution from an elevated, continuously emitting point source is given by the Gaussian plume formula. However, following Meade and Pasquill (1958), this formula was first modified to give the long-term average concentration produced by a given source at any receptor for specified frequencies of occurrence of the various possible wind directions. Martin and Tikvart utilized this result in conjunction with a specified joint frequency function for the occurence of various possible combinations of wind direction, wind speed, and atmospheric stability to obtain the long-term average concentration for all the possible combinations of the meteorological conditions for a multiple source distribution.

The model clearly represents a natural development in the hierarchy of urban air pollution models that stem directly from the Gaussian plume hypothesis. The present paper provides a detailed account of the model which has not been previously available. Revisions have been incorporated to clarify some features of the original analysis. A major revision relates to the mathematical method for computing the concentration contributions from area-source distributions.

II. THE GAUSSIAN PLUME

A recent discussion of the structure and assumptions that underlie urban air pollution models based on the Gaussian plume has been given elsewhere (Calder, 1969). The common starting point is the assumption that meteorological conditions over short periods of time of the order of an hour can be regarded as steady-state. It is also assumed that these conditions may be adequately approximated with a unique horizontal mean wind direction for the entire urban area together with a constant and spatially uniform wind speed.

Let the origin of a rectangular coordinate system be taken at ground level, with the x-axis in the direction of the mean wind, y-axis crosswind and the z-axis vertical. Then for a constant, continuously emitting, elevated point-source of strength G located at $x=0$, $y=0$, $z=h$, the Gaussian plume formula gives the concentration $\chi(x, y, z)$ of material at position (x, y, z) as

$$\chi(x, y, z) = G\left[\frac{\exp\left(-\frac{y^2}{2\sigma_y^2(x)}\right)}{\sigma_y(x)\sqrt{2\pi}}\right] S(x, z) \tag{1}$$

where

$$S(x, z) = \frac{1}{U\sigma_z(x)\sqrt{2\pi}}\left[\exp\left(-\frac{(z-h)^2}{2\sigma_z^2(x)}\right) + \exp\left(-\frac{(z+h)^2}{2\sigma_z^2(x)}\right)\right] \tag{2}$$

and $\sigma_y(x)$, $\sigma_z(x)$ are horizontal and vertical diffusion functions that give respectively, the horizontal and vertical standard deviations of the Gaussian concentration distribution at downwind distance x. The above formula relates to the atmospheric transport and diffusion of a chemically stable gas or a cloud of particles sufficiently small that gravitational settling can be neglected. It is also assumed that no material is lost from the cloud to the ground surface. The method of images is invoked to satisfy this condition and the function S(x, z) is the sum of two terms representing (in the absence of the ground surface) the concentration contribution from the real source at z = h and that from its image in the plane z = 0, i.e., at z = -h. It is readily verified that equation (1) satisfies the equation for the conservation of matter, namely

$$\int_{-\infty}^{\infty}\int_{0}^{\infty} U\chi\,(x, y, z)\,dydz = G \qquad (3)$$

Equation (1) is assumed to be valid irrespective of the horizontal location of the source and of the horizontal mean wind direction that defines the orientation of the coordinate system.

The standard deviation functions $\sigma_y(x)$ and $\sigma_z(x)$ are dependent on meteorological conditions and are assumed to be parameterized in terms of an atmospheric stability category P first introduced in discussions of atmospheric diffusion by Pasquill (1961). Actually, a completely objective scheme for determing the appropriate stability category in terms of meteorological observations that are routinely taken at airports was suggested by Turner (1964) and used in the application of the model. This scheme admits five different Pasquill-type stability categories P_m(m = 1, 2, 3, ..5) for an urban environment, P_1 being a very unstable category and P_5 a slightly stable one. For given stability category P_m the standard deviation functions $\sigma_y(x; P_m)$ and $\sigma_z(x; P_m)$ are obtained as functions of the downwind distance x from some graphical plots of Gifford (1961). The latter are simple transforms of some rather crude empirically established dispersion curves first given by Pasquill (1961, 1962). For the final computerized model, it is convenient to represent the Gifford plots by simple formulae of the type

$$\sigma_z(x;\ P_m) = ax^b + c$$

where for each stability category a, b, c, are constants within given ranges of x.

The above values of $\sigma_z(x;\ P_m)$ refer to conditions where there are no restrictions to diffusion in the vertical direction so that $\sigma_z(x;\ P_m)$ increases continually with x. However, when a stable atmospheric layer exists above an unstable near-surface layer, the vertical diffusion will be limited to a mixing layer of finite depth L, within which pollutants will be trapped. If this occurs, a uniform vertical distribution of concentration would be expected throughout the depth of the mixing layer for sufficiently large values of x and some modification of the Gaussian formula will be necessary. Providing that the emission height h is small compared with L, a crude but simple method of allowing for this effect has been suggested by Pasquill (1962) and Turner (1969). By assigning h = 0 in the equation (2), it is readily verified that, when $z = 2.15\ \sigma_z$, the concentration is one-tenth its value at the ground surface. When this value is occurring at the level of the top of the mixing layer, it is assumed that the "lid" begins to influence appreciably the vertical distribution of concentration. Turner suggests the following rough method to allow for the situation. Use equations (1) and (2) for downwind distances such that $\sigma_z(x) \leq L/2.15$ or $\sigma_z(x) \leq 0.47\ L$ corresponding to downwind distances, say x_L. Assume that for $x \geq 2x_L$ the concentration has become uniform through the depth of the mixing layer, so that S(x, z) of equation (2) is replaced by

$$S(x,\ z) = \frac{1}{L} \quad (x \geq 2x_L) \tag{4}$$

For $x_L \leq x \leq 2x_L$, Turner suggests linear interpolation between the concentration values for these two distances. This procedure was adopted in the Martin-Tikvart air pollution model.

A more refined method of correcting for the finite depth of the mixing layer is to utilize the "method of images" in the same manner that this technique is used to allow for the "reflecting" ground surface in establishing the function S of equation (2). For a point source situated between two parallel "reflecting" surfaces at distance L apart, i.e., the ground and the lid of the mixing layer, it is evident that an infinite series of image sources arises and the concentration distribution is thus expressed as an infinite series [Bierly and Hewson (1962), Fortak (1969)]. In this case it is readily shown

$$\chi(x, y, z) = \frac{G}{2LU} \left(\frac{\exp\{-\frac{y^2}{2\sigma_y^2}\}}{\sigma_y(x)\sqrt{2\pi}} \right) \left[\Lambda\{\frac{z-h}{2L}; \frac{\sigma_z^2}{2L^2}\} + \Lambda\{\frac{z+h}{2L}; \frac{\sigma_z^2}{2L^2}\} \right] \tag{5}$$

where the function Λ is defined by

$$\Lambda(v;w) \equiv \frac{1}{\sqrt{\pi w}} \sum_{n=-\infty}^{+\infty} \exp\{-\frac{(v+n)^2}{w}\} \tag{6}$$

When $L \rightarrow \infty$, only the term corresponding to $n = 0$ remains in each of the two infinite series that are involved, and in this case (5) reduces to (1) with S given by (2). In the general case the infinite series converge rapidly, and it is only necessary to consider a few terms.

Before leaving this discussion of the Gaussian plume, it should be noted that the emission height h for large point sources can rarely be taken as the actual physical height of a pollutant emitting stack since there is normally consideable plume rise associated with the upward momentum of discharge and therml buoyancy effects. Frequently a crude attempt to allow for these effects ismade by simply adding an estimate of the plume rise to the stack height andusing this sum as the quantity h in the diffusion formulae. Consideration ofplume rise is a complicated and somewhat controversial topic, although it is gnerally regarded as an important element in realistic urban air pollution models. A comprehensive and hopefully definitive critical review of the subject has been recently prepared by Briggs (1969).

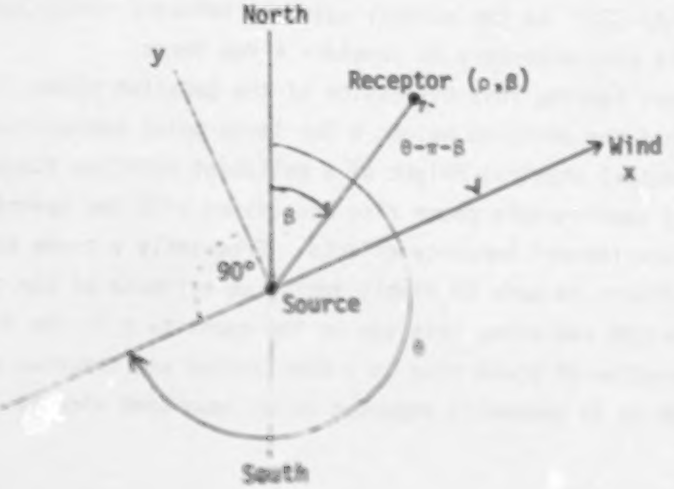
III. AVERAGE CONCENTRATION WITH VARIABLE WIND DIRECTION FROM A SINGLE SOURCE

For fixed locations of both source and receptor, the maximum concentration will occur at the receptor when the wind blows directly from the source towards the receptor. The concentration varies with wind direction. Therefore, the average value when the wind direction is a random variable governed by a probability or frequency distribution is considered first.

Relative to a rectangular coordinate system with x-axis along the wind direction, the point source concentration distribution will be given by equation (1), where

$$GS(x, z) = \int_{-\infty}^{\infty} \chi(x, y, z)\, dy \qquad (7)$$

In the diagram below, let the source be at the origin of a polar coordinate system, with (ρ,β) the polar coordinates of the receptor, and θ the angular direction measured clockwise from north from which the wind blows.



Then if $f(\theta)d\theta$ is the probability that the wind direction is in the angular range θ, $\theta + d\theta$, the average concentration at the receptor corresponding to all possible wind directions will be approximated by

$$\overline{\chi} = \int_{\pi+\beta-\Delta}^{\pi-\beta+\Delta} \chi(\rho\cos\overline{\theta-\beta-\pi}, \rho\sin\overline{\theta-\beta-\pi}, z)\ f\ (\theta)d\theta \qquad (8)$$

where, since the plume from a point source is normally narrow, Δ is a small angle. If the total range of integration were made larger than 2Δ, this would have negligible effect on the value of the integral. With $\psi = \theta - \beta - \pi$, equation (8) becomes

$$\overline{\chi} = \int_{-\Delta}^{\Delta} \chi(\rho\cos\psi, \rho\sin\psi, z)\ f\ (\psi + \beta + \pi)d\psi$$

or since ψ is small and hence $\cos\psi \simeq 1$, we have, using equation (1),

$$\overline{\chi} = \frac{GS(\rho, z)}{\sigma_y(\rho)\sqrt{2\pi}} \int_{-\Delta}^{\Delta} e^{\frac{-\rho^2\sin^2\psi}{2\sigma_y^2(\rho)}}\ f(\psi + \beta + \pi)d\psi \qquad (9)$$

The integral in (9) could be evaluated numerically if the frequency function were specified. However, with small ψ, we have approximately

$$\overline{\chi} = \frac{GS(\rho, z)}{\sigma_y(\rho)\sqrt{2\pi}} \int_{-\Delta}^{\Delta} e^{\frac{-\rho^2\psi^2}{2\sigma_y^2(\rho)}}\ f(\psi + \beta + \pi)d\psi \qquad (10)$$

We now assume that, because of the smallness of the angular range $-\Delta \leq \psi \leq \Delta$, the variations of the wind direction frequency function in the integral of (10) can be disregarded and the function replaced by its central value $f(\beta + \pi)$

so that

$$\overline{\chi} = \frac{GS(\rho,\ z)}{\sigma_y(\rho)\sqrt{2\pi}}\ f(\beta + \pi) \int_{-\Delta}^{\Delta} e^{\frac{-\rho^2\chi^2}{2\sigma_y^2(\rho)}}\ d\psi = \frac{GS(\rho,\ z)}{\rho}\ f(\beta + \pi) \int_{-\frac{\rho\Delta}{\sigma_y}}^{\frac{\rho\Delta}{\sigma_y}} \frac{1}{\sqrt{2\pi}}\ e^{\frac{-w^2}{2}}\ dw \tag{11}$$

The integral is recognized as that of the Gaussian probability function whose value tends to unity when both limits of the integration tend to infinity. However, the value of $\overline{\chi}$ is not affected by increasing the value of Δ as it appears in the limits of integration, which can only be so if the integral differs inapreciably from its asymptopic value of unity. With this approximation, we have

$$\overline{\chi} = \frac{GS(\rho,\ z)}{\rho}\ f(\beta + \pi) \tag{12}$$

It may be noted that:

1) although both equations (9) and (10) for $\overline{\chi}$ involve the crosswind standard deviation function $\sigma_y(\rho)$, this is not so for the final approximate relation (12) which is independent of $\sigma_y(\rho)$.

2) equation (12) expresses $\overline{\chi}$ as the product of an "isotropic" meteorological-diffusion function $GS(\rho,\ z)/\rho$ and the directionally dependent wind frequency function.

3) although $\overline{\chi}$ is the average concentration at the receptor corresponding to all possible wind directions, the narrow plume assumption renders it possible to relate this average value to the frequency function for a particular wind direction, viz. the source receptor direction.

With a 16-point compass if all wind directions within any given 22 1/2° sector are equally probable, then if the source-receptor direction [here defined by the angle $(\beta + \pi)$] is in the k-th sector (k = 1, 2, ... 16) ad

$F(k)$ is the total frequency of wind directions in the k-th sector, we have

$$f(\beta + \pi) \times \frac{2\pi}{16} = F(k)$$

so that from (12)

$$\overline{\chi} = \frac{16}{2\pi} F(k) \frac{GS(\rho, z)}{\rho} \qquad (13)$$

With an 8-point compass the corresponding formula would be identical with one used by Meade and Pasquill (1958) in examining the average distribution of sulfur pollution around a power station in the U.K.

In the analysis leading to equation (13), only wind direction is considered to be a random variable. However, it is straightforward to generalize where several meteorological variables are regarded as random with values specified through a joint frequency function. Thus assume that the wind direction (defined by sectors $k = 1, 2, \ldots 16$), the urban wind speed* U_ℓ ($\ell = 1, 2, \ldots 6$), and the Pasquill-type stability category P_m ($m = 1, 2, \ldots 5$) are such random variables having a joint frequency function $\phi(k, \ell, m)$ that expresses the relative frequency with which the wind is in the k-th sector with representative speed U_ℓ and stability category P_m. Such a three-variable joint frequency function was first used in the context of the present problem by Leavitt (1960) and subsequently by Szepsi (1964, 1967). Evidently in equation (13) the diffusion function $S(\rho, z) \equiv S(\rho, z; U_1, P_m)$ where, from equation (2), S involves P_m through the standard deviation function $\sigma_z(\rho) \equiv \sigma_z(\rho; P_m)$. It immediately follows from equation (13) that the average concentration $\overline{\chi}$ corresponding to all possible combinations of wind direction, wind speed, and stability will be given by

$$\overline{\chi} = \frac{16}{2\pi} \sum_{\ell} \sum_{m} \frac{\phi(k, \ell, m) GS(\rho, z; U_\ell P_m)}{\rho} \qquad (14)$$

---

*Here wind speed is assumed to be specified in terms of one of the standard Weather Bureau classes (i.e., with wind estimated to an integral number of knots in the classes 0-3, 4-6, 7-10, 11-16, 17-21, and > 21 knots) and each class is represented by its central wind speed (i.e., 0.67, 2.46, 4.47, 6.93, 9.61, 12.52 meters per sec).

where as before the source-receptor direction is assumed to lie in the k-th wind section (N.B. the summation in equation (14) does not involve k). A virtuallly identical solution was first proposed by Szepsi (1964). In principle the Martin-Tikvart model simply sums equation (14) for a given receptor location over the multiplicity of contributing sources.

It is important to note that the summand in equation (14) cannot legitimately be used, as is attempted by Szepsi (1967), as a basis for analysis of the frequency occurrence of various levels of concentration. This is because it was obtained through averaging over all possible wind directions. It is this averaging process that eliminates the crosswind variance function $\sigma_y(\rho)$ that appears in the original point-source concentration distribution function of equation (1).

IV. THE MULTIPLE SOURCE POLLUTION MODEL

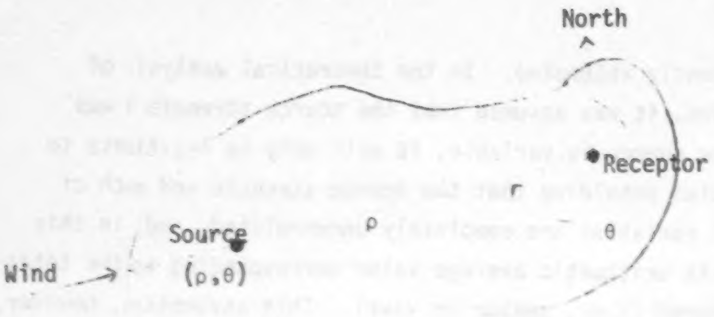
It is customary in estimating community air pollution emissions from fixed sources [e.g. Ozolins and Smith(1966)] and in modeling urban air pollution to distinguish between two main categories of pollutant sources. Very large sources with emissions in excess of 100 tons per year are readilyidentified and located individually as single (elevated) point-sources. However, when there are a large number of small sources too numerous to identify individually such as domestic heating units, then it is normal to combine these sources in any small area and to specify them through the total pollutant emission associated with the area. The size and number of the sub-areas are chosen in relation to the spatial uniformity of the source distribution. Thus a complete urban pollution emissions inventory for stationary sources will normally comprise the strenths and locations of all major point sources together with area-source strengths corresponding to a large number of area elements into which the total urban area has been sub-divided. In most emission inventories, it is difficult or impossible to specify with accuracy much detail concerning the temporal variations of the emissions, although an estimate of variation from season to season is frequently attempted. In the theoretical analysis of the previous section, it was assumed that the source strength G was constant. When the source is variable, it will only be legitimate to use the same formulae providing that the source strength and each of the meteorological variables are completely uncorrelated, and, in this case, G is given its arithmetic average value corresponding to the total time period considered (i.e., season or year). This assumption, however, may be questionable in some circumstances. For example, in winter very cold conditions with increased air pollution due to increased fuel consumption may occur most frequently with certain wind directions. If the source strength and meteorological conditions are not uncorrelated, a more sophisticated development is required that is outside the scope of the present analysis. Although this may be straightforward mathematically, the serious practical questions of specifying short-term temporal variations of source strength have yet to be resolved.

Considering equation (14) it is evident that if $k_n (k_n = 1, 2, \ldots 16)$ is the wind sector appropriate to the n-th point source (of strength G_n and distance ρ_n from receptor) and there are N point sources, then the average total concentration at the receptor, $\overline{C}_p$, due to all the point sources will be given by

$$\overline{C}_p = \frac{16}{2\pi} \sum_{n=1}^{N} \sum_{\ell} \sum_{m} \frac{\phi(k_n, \ell, m) G_n S(\rho_n, z; U_\ell, P_m)}{\rho_n} \qquad (15)$$

Obviously the contribution to the total from just those sources located in the k-th sector will be obtained by restricting the summation to these sources (i.e., those for which $k_n = k$).

To obtain the concentration contribution, say $\overline{C}_A$, at the receptor due to the area-soruce distribution we use a polar coordinate system with origin at the receptor and with angle θ measured clockwise from north as in specifying the wind direction.



An element of area surrounding the point (ρ,θ) will have magnitude ρdθdρ. Let Q(ρ,θ) denote the magnitude (emission rate per unit area and unit time) of the area source strength at (ρ,θ), so that Q(ρ,θ) ρdθdρ is the total emission rate from the element of area surrounding (ρ,θ). Then by considering the area source contributions from the different 22 1/2° wind sectors, it immediately follows from (15) that the total average concentration due to the area-source distribution will be*

$$\bar{c}_A \quad \frac{16}{2\pi}\sum_{k=1}^{16}\sum_{\ell}\sum_{m}\phi(k,\ell,m)\int_0^\infty \frac{S(\rho,z;U_\ell,P_m)}{\rho}\left\{\int_{k\text{ sector}} Q(\rho,\theta)\rho\,d\theta\right\}d\rho \tag{16}$$

Here the upper limit of integration for ρ can be taken as infinite since Q(ρ,θ) becomes zero outside the domain of the area-source distribution. Equation (16) can be rewritten as

---

*In equation (16), it is assumed that the effective height of the area source distribution can be regarded as a constant for the entire area. This is an assumption made in the original Martin-Tikvart Model. If the height is variable then the function S becomes a function of θ and cannot be taken outside the sector integral sign in equation (16). This, of course, raises no fundamental problem but complicates the numerical integration.

$$\overline{C}_A = \frac{16}{2\pi} \int_0^\infty \left\{ \sum_{k=1}^{16} q_k(\rho) \sum_{\ell} \sum_{m} \phi(k, \ell, m)\, S(\rho, z; U_\ell, P_m) \right\} d\rho \tag{17}$$

where

$$q_k(\rho) \equiv \int_{k\ \text{sector}} Q(\rho,\theta)d\theta$$

so that $\frac{16}{2\pi}\, q_k(\rho)$ is the average value of Q in the k-th sector at a radial distance ρ. Evidently, if the integral in (17) is replaced by just a single term of its sum we obtain the average concentration from area sources lying within the corresponding wind sector.

The total average concentration $\overline{C}$ at the receptor due to both point and area sources is given by $\overline{C} = \overline{C}_A + \overline{C}_p$.

In applying equation (17), we have to determine for each receptor location the source functions $Q(\rho,\theta)$ and $q_k(\rho)$. The air pollution emission inventory for a stationary area source distribution is, of course, specified once and for all for areas of fixed locations on a map of the urban area. A typical inventory as used in the St. Louis Study referred to in a later section may divide the entire urban area into 5000 ft. squares with a seasonal emission rate assigned for each square. However, from such an inventory, it is simple to determine, for any given values of the polar coordinates relative to a selected receptor location, the appropriate numerical values of the source function $Q(\rho,\theta)$. The sector function $q_k(\rho)$ may then be determined by numerical integration of the values of $Q(\rho,\theta)$ along the appropriate circular arc. For this purpose the trapezoid rule of numerical integration was applied on each arc to Q-values spaced 2 1/4° apart, i.e., the 22 1/2° arc was subdivided into ten intervals. The second integration with respect to the radial distance ρ as required in equation (17) was also performed numerically by the trapezoid rule with an interval length in ρ of 100 meters.

V. MODEL INPUT DATA AND PARAMETERS

A basic feature of the present model is the assumption that for short time periods (of the order of one hour) meteorological conditions can be regarded as steady and uniform over the entire urban area and may be specified through some single representative value for wind direction, wind speed, stability category, and mixing depth. Since detailed urban meteorological observations are not normally available, it may be necessary in practice to utilize information collected at some nearby airport weather station with the assumption that this is roughly representative of the urban area. Thus, in using the Martin-Tikvart model to estimate seasonal or annual urban air quality, the standard hourly Weather Bureau data from the local airport station is normally used. The climatological joint frequency function $\phi(k, \ell, m)$ of the model can be readily obtained from the hourly airport observations using a computer program specially developed for this purpose by J. Tikvart.

The objective method proposed by Turner (1961, 1964) is used to estimate the hourly atmospheric stability category P_m at the airport. This method requires no vertical sounding data but is based on ground-level meteorological observations only (surface wind speed, cloud amount and height) supplemented by solar elevation data (latitude, time of day, and time of year).

The values of the standard deviation function $\sigma_z(x; P_m)$ used in the application of the model are those of Pasquill (1961) and Gifford (1961) and represented for the computation in the form

$$\sigma_z(x; P_m) = ax^b + c$$

where a, b, c are constants for each stability category, as shown in the following table.

	Stability Category					Distance
	1	2	3	4	5	x (Meters)
a	.001	.048	.119	2.610	52.600	>1000
	.001	.048	.119	.187	.136	100-1000
	.174	.163	.23	.080	.060	<100

Stability Category

	1	2	3	4	5	Distance x(Meters)
b	1.890	1.110	.915	.450	.150	>1000
	1.890	1.110	.915	.755	.745	100-1000
	.936	.922	.905	.881	.845	<100
c	9.600	2.000	.000	-25.500	-126.000	>1000
	9.600	2.000	.000	-1.400	-1.100	100-1000
	.000	.000	.000	.000	.000	<100

The values of $\sigma_z(x; P_m)$ described above were originally established from diffusion experiments conducted over flat and relatively smooth rural terrain. To make some crude allowance for the thermal and mechanical influences of the urban area, two types of correction have been suggested and are used with the model. The first is intended to reflect the fact that the lowest part of the typical urban atmosphere is less stable than its rural counterpart. To take this into account during the daytime a stability category one step more unstable than for the "rural" airport situation is used, i.e., m is decreased by unity except for the case m = 1, for all the area source calculations. When the rural stability category is P_5, corresponding to a nighttime surface inversion, the neutral stability category P_4 is assumed to apply for both the area and point source calculations in the urban situation (so that for urban applications the values of the constants a, b, c above are not needed for P_5).

The second modification of the values of $\sigma_z(x; P_m)$ attempts to incorporate an experimental finding of Pooler (1966) that for low level releases of tracer material in an urban area the data are best represented by assigning an initial value σ_{z_0} at x = 0. [Note in the above table of σ-values σ = 0 as x = 0.] This initial value is added to the Pasquill-Gifford values obtained from the table above. In the urban air pollution model, an initial value of 30 meters is assumed for low level sources (an effective source height of 20 meters or less). Arbitrarily this initial value is decreased linearly to zero as the effective source height increases to 50 meters and is then taken as zero when the source height exceeds 50 meters. In all cases it is convenient to incorporate the effect of the initial σ_o by use of the virtual source concept, i.e., by regarding the σ_o-values as the result of diffusion from an imaginary source located upwind of the real source and then adding the virtual source distance to the actual physical distance.

The mixing depth L that occurs in the formulation of the model varies greatly diurnally, seasonally, and annually. Since it is impractical to account for all these variations, a procedure reflecting only major changes is used. The procedure determines an effective mixing depth by modifying the average maximum (afternoon) mixing depths, as tabulated by Holzworth (1964), depending on the stability category being considered. Stability categories P_1, P_2, P_3, are afternoon conditions, with P_1 corresponding to very unstable conditions. With P_1, the value of L is assumed to be 50% greater than the climatological value tabulated by Holzworth; with P_2 or P_3 the climatological value is adopted. According to the objective criteria of Turner, the stability category P_5 can only occur at night under conditions when ground-based inversions would occur over open level country. Since a shallow layer of neutral or weak lapse conditions has been found to occur over urban areas, even with strong nocturnal surface inversions in the surrounding rural areas, a mixing depth L = 100 meters is adopted for stability category P_5, when the latter is indicated by the objective criteria. The 100-meter value is suggested by some observations of Clarke (1969). Stability category P_4 is a neutral stability condition that may occur either during the day or at night. In the present version of the model, it was divided into day and night sub-classes. The Holzworth climatological mean value was associated with a daytime case, and the arithmetic average of the daytime value and the 100-meter value above associated with a nighttime case.

To apply the Martin-Tikvart model, it is necessary to estimate the effective heights of pollutant emission for both the area and point sources. For the low level area sources (predominately residential and commercial heating), an average height emission may be estimated roughly from consideration of building heights. It is not usual to apply any correction for plume rise to these small sources. In the application to St. Louis, Missouri, considered in the next section, a constant effective height of 20 meters was assumed for all the area sources. As previously indicated, if this height is not considered constant for the entire urban area, it is necessary to modify the procedure for numerical evaluation of the area source concentration integral of equation (17). For the large point sources considered through equation (15), the effective source height h is determined from the physical stack height h* and the estimated plume rise Δh, i.e., $h = h^* + \Delta h$. The plume rise equation used in the original Martin-Tikvart model (and in the calculations of the next section) is from Holland (1953) and is given by

$$\Delta h = \frac{V_s d}{U} [1.5 + 2.68 \times 10^{-3} P (\frac{T_s - T_a}{T_s}) d]$$

where V_s = stack gas exit velocity (meters/sec)

d = stack exit diameter (meters)

U = mean wind speed (meters/sec)

P = atmospheric pressure (mb)

T_s = stack gas exit temperature (°K)

T_a = ambient air temperature (°K)

Since this equation is appropriate for the neutral stability condition, it must be modified for application over a range of stability conditions. The following modification has been used to allow for a range from 1.3 Δh for very unstable conditions to $0.9\Delta h$ for the most stable.

$$h = h^* + \Delta h(1.4 - 0.1\ m) \quad (m = 1, 2, 3, 4, 5)$$

and is a crude attempt to account for the increase of plume rise with decreasing stability. However, it is recommended that for future applications the old plume rise formula of Holland should be replaced with the more recent ones suggested by Briggs (1969).

Finally, note that for some point sources (e.g. power plants with tall stacks), the effective emission height ($h^* + \Delta h$) may be greater than the mixing depth when the latter is small. On the assumption that the plume will not diffuse downward through the stable layer, these cases are identified and eliminated from consideration in the Martin-Tikvart model.

VI. AN APPLICATION WITH DISCUSSION

The model was originally applied in 1968 to the calculation of average sulfur dioxide concentrations during the winter months (1 Dec. 1964 to 28 Feb. 1965) for St. Louis, Missouri, since comprehensive data was available from a special air pollution study (Farmer and Williams, 1966). However, the data on emissions inventory, air quality, and meteorological conditions that are used in the present calculations were specially compiled by Turner and Edmisten (1968). The area-source emissions inventory was provided for 1200 squares (30 x 40); each square was 5000 ft. on a side. This area completely surrounded a central region of 17 x 19 squares within which an air quality network of 40 sampling stations with 24-hour SO_2 bubblers was located for the 3-month period. In addition, 62 major point sources were considered individually in the emissions inventory. The meteorological joint frequency distribution required for use with the model was determined from hourly observations covering the 3-month period at the Lambert Field Weather Bureau. As the topography is relatively flat and umcomplicated, the observations are assumed to be representative of the entire St. Louis area. In effect, the joint frequency function pre-digests the meteorological data into a discrete number of possible cases. Since wind speed is classified into 6 categories, wind direction into 16 categories, and stability into 6 categories (here with differentiation between nighttime and daytime category 4), the distribution covers 6 x 16 x 6 = 576 cases. Finally, the average climatological mixing depth was estimated from rawinsonde observations made at neighboring Columbia, Missouri, and Peoria, Illinois. The mean depth for the three winter months in question was 800 meters.

Calculations of average air quality were made using an IBM 360-50 computer, and the running time was 1.6 minutes per receptor location. An IBM 1130 was then used to calculate regression lines of observed versus calculated concentrations, and, by coupling with a CALCOMP plotter*, also to generate the isopleths of average pollution concentrations that follow. The results of several different calculations are given in Figures 2 through 7.

Figure 1 is a computer generated map of the isopleths of 3-month average observed SO_2 concentrations (in $\mu g/m^3$) for the central area of 17 x 19 squares in which the air quality network was located. Figure 2 is the isopleth map for the average concentrations as calculated by straightforward application of the model, and Figure 3 is a corresponding regression of the observed versus calculated values for the 40 sampling stations of the network. If y and x denote observed and calculated values, respectively, then

$$y = 0.26x + 19.98$$

with a correlation coefficient $r = 0.775$. Therefore, in this case, the model overcalculates the average concentrations by an appreciable factor. In an attempt to improve agreement with observations, calculations were also made employing some simple modifications of the basic model. The latter only uses a single representative wind speed for a given time and thus disregards the known increase of wind speed with height above the ground. However, a wind speed more prepresentative of the transport and diffusion of pollutant from large, elevated point sources would probably be that estimated to occur at the appropriate effective height for each point source. A crude estimate of this speed may be made by extrapolating the surface speed (actually the 10-meter airport wind) using a simple power law of the form

$$\frac{u(z)}{u(z_1)} = \left(\frac{z}{z_1}\right)^p$$

where, following DeMarrais (1959), the exponent p is taken to be a function of the stability category. For the present calculations, the following values were assumed

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*CALCOMP is the manufacturer's name for an X-Y plotter that is used to generate the isopleths. The program for this operation is an IBM routine entitled "Numerical Surface Techniques and Contour Map Plotting" (113-CX-11X).

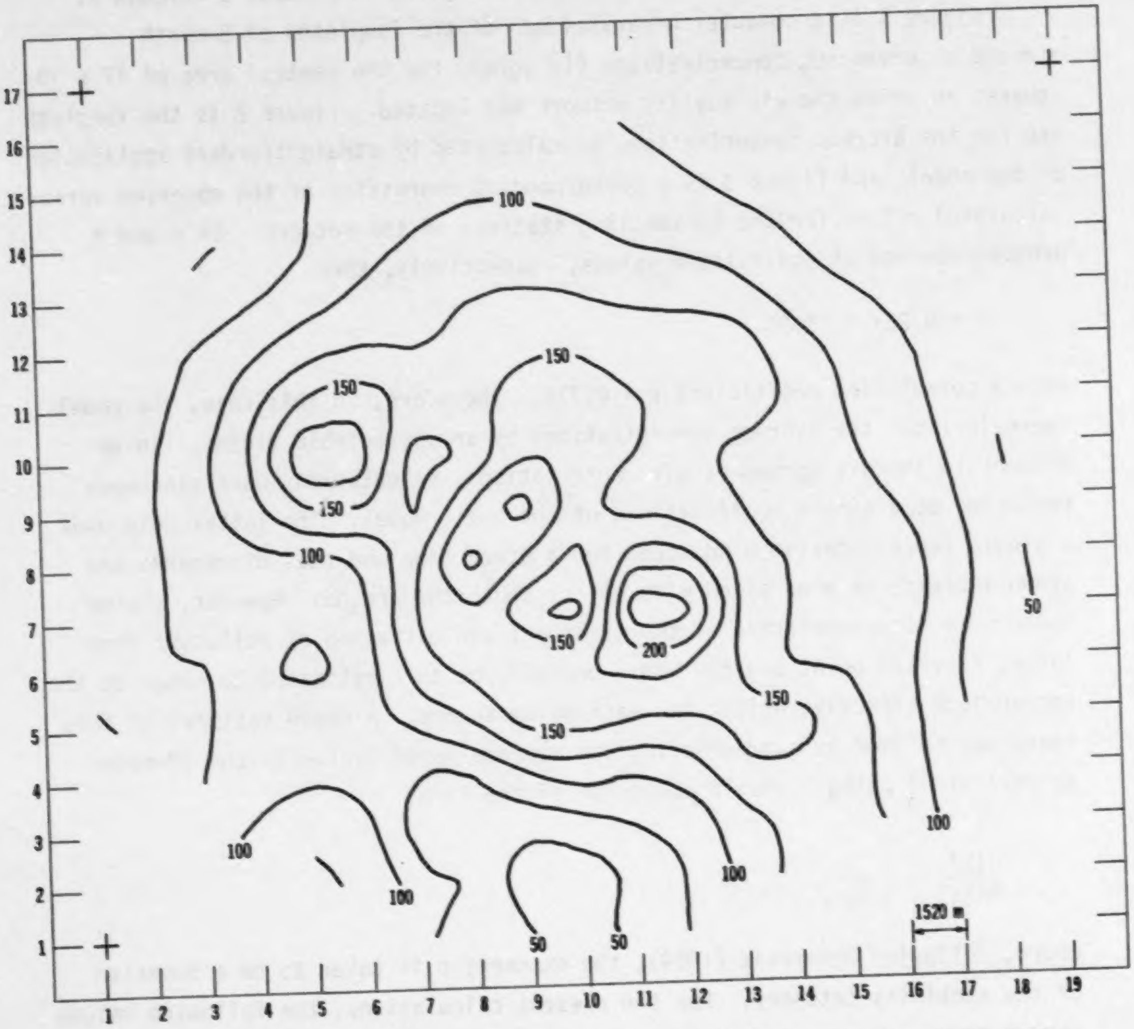
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Figure 1. Isopleths of observed average SO_2 concentration ($\mu g/m^3$) for period December 1, 1964, through February 28, 1965.

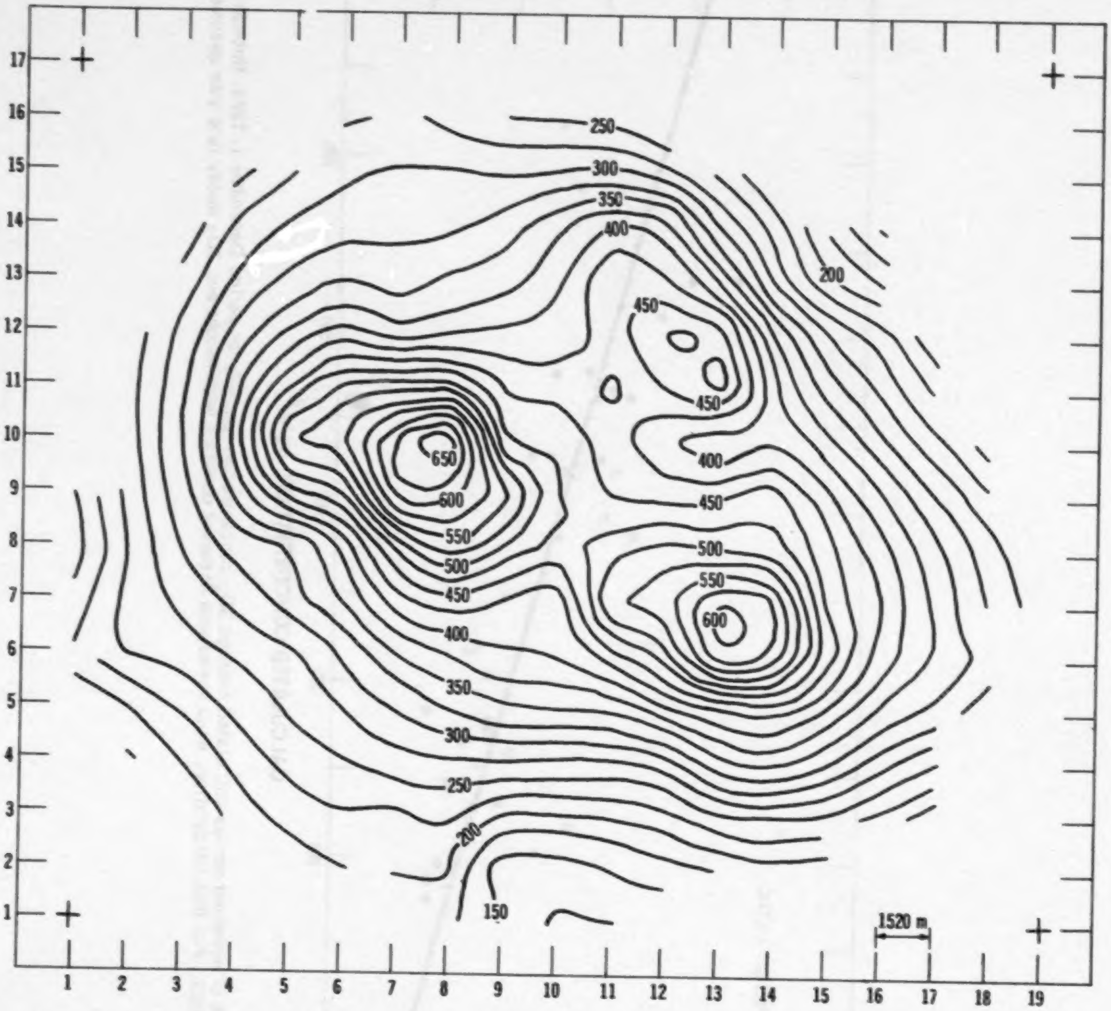
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Figure 2. Isopleths of computed average SO_2 concentration ($\mu g/m^3$) for the period December 1, 1964, through February 28, 1965. For this calculation, wind speed was assumed constant with height and SO_2 decay rate was assumed to be zero.

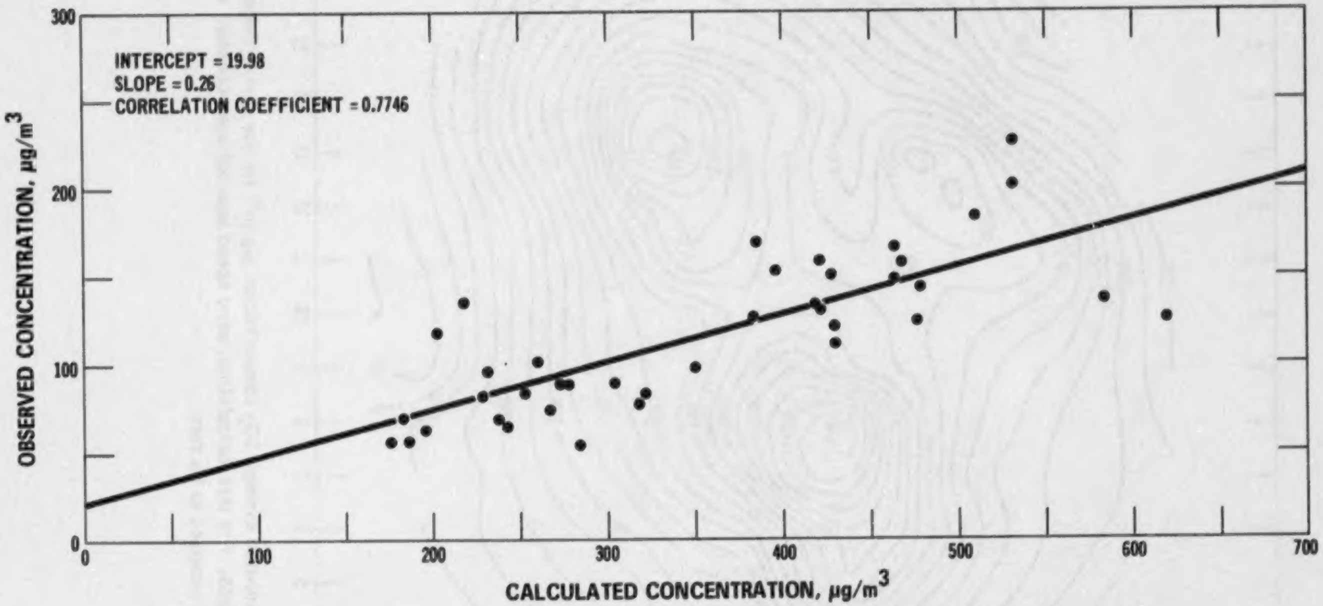

Figure 3. Regression line of observed versus calculated average SO_2 concentration ($\mu g/m^3$) for period December 1, 1964, through February 28, 1965. For this calculation, wind speed was assumed constant with height and SO_2 decay rate was assumed to be zero.

Stability category	1	2	3	4	5
P	0.1	0.15	0.2	0.25	0.3

The results of calculations made on this basis are shown in Figure 4 and 5. Figure 4 shows the calculated concentration isopleths, while Figure 5 shows the regression of the observed on calculated values. In this case,

$$y = 0.32x + 20.26$$

with a correlation coefficient $r = 0.772$. Again, the model overcalculates although to a slightly smaller degree. The final set of calculations, represented in Figures 6 and 7, were made to provide some indication of the effect of assuming that SO_2 pollutant is subject to some removal process in the atmosphere which might considerably reduce the ground-level concentrations. A recent paper (Weber, 1970) indicates that, depending on the meteorological conditions, a loss of almost 50% may occur in a period of 20 minutes to 1 hour. Calculations were, therefore, made assuming an exponential decay of SO_2 with travel time using a half-life value $T_{1/2} = 30$ minutes (also a single representative wind speed was assumed for these calculations). Figure 6 shows the isopleths based on the calculated values, and Figure 7 shows the regression line of observed on calculated values. In this case

$$y = 0.39x + 52.05$$

with a correlation coefficient $r = 0.786$. Thus, in spite of the high decay rate, the model still systematically overcalculates the average concentration values.

Unambiguous reasons for this feature are not clear, although a number of possibilities are under study at the present time. Some of the probable shortcomings of the model are identified in the discussion that follows. Although the model is conceptually quite simple, the superposition of the effects produced by a complex distribution of pollution emissions and under a complex sequence of meteorological conditions quickly obscure the simpler quantitative properties of the model in the massive details of particular

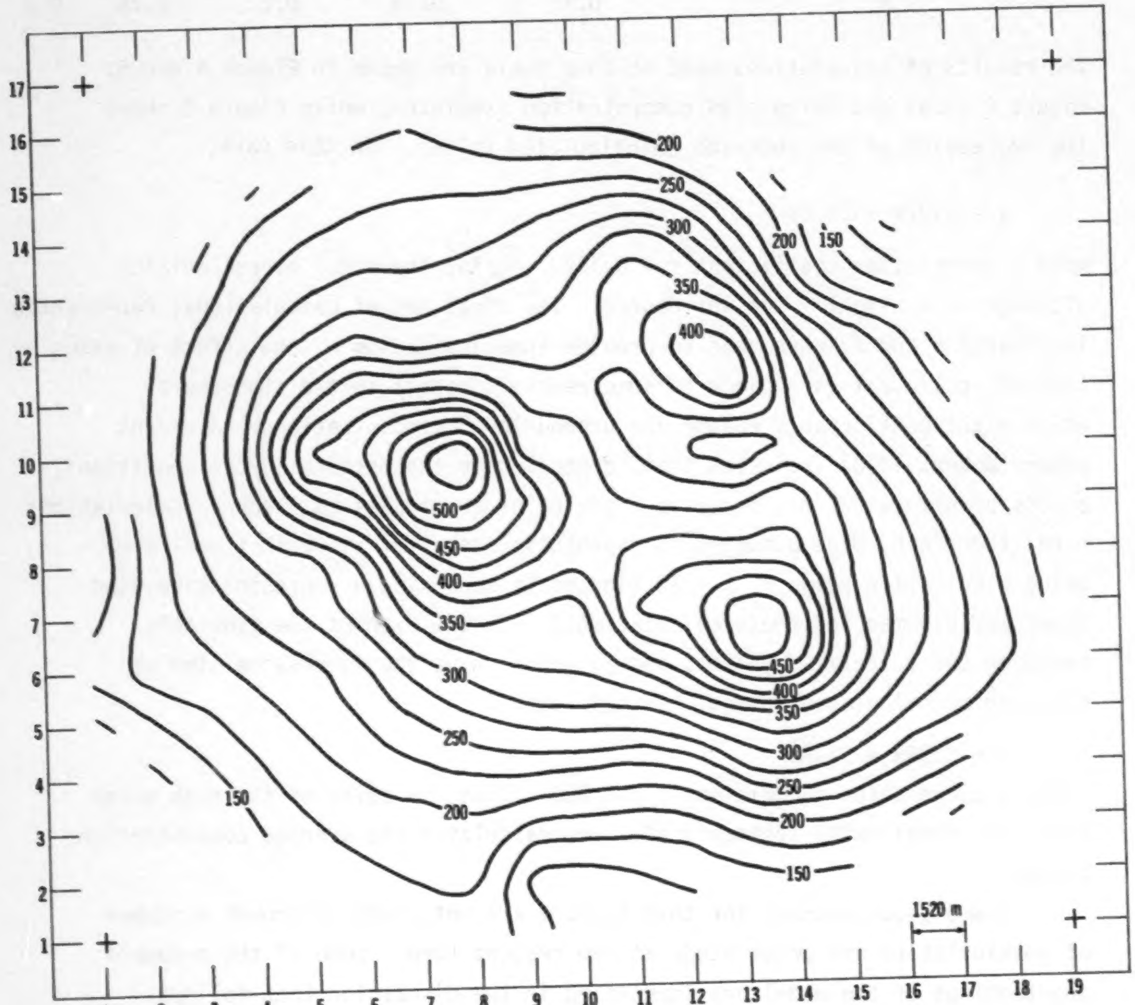
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Figure 4. Isopleth of computed average SO_2 concentration ($\mu g/m^3$) period December 1, 1964, through February 28, 1965. For this calculation, a power-law wind profile was introduced and SO_2 decay rate was assumed to be zero.

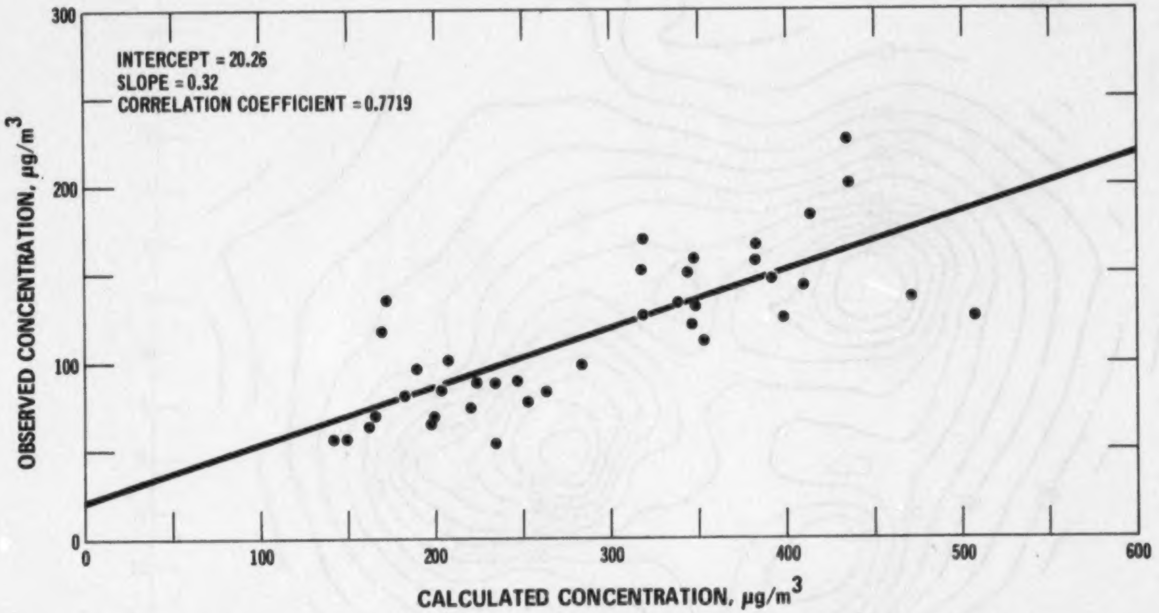

Figure 5. Regression line of observed versus calculated average SO_2 concentration ($\mu g/m^3$) for period December 1, 1964, through February 28, 1965. For this calculation, a power-law wind profile was introduced and SO_2 decay rate was assumed to be zero.

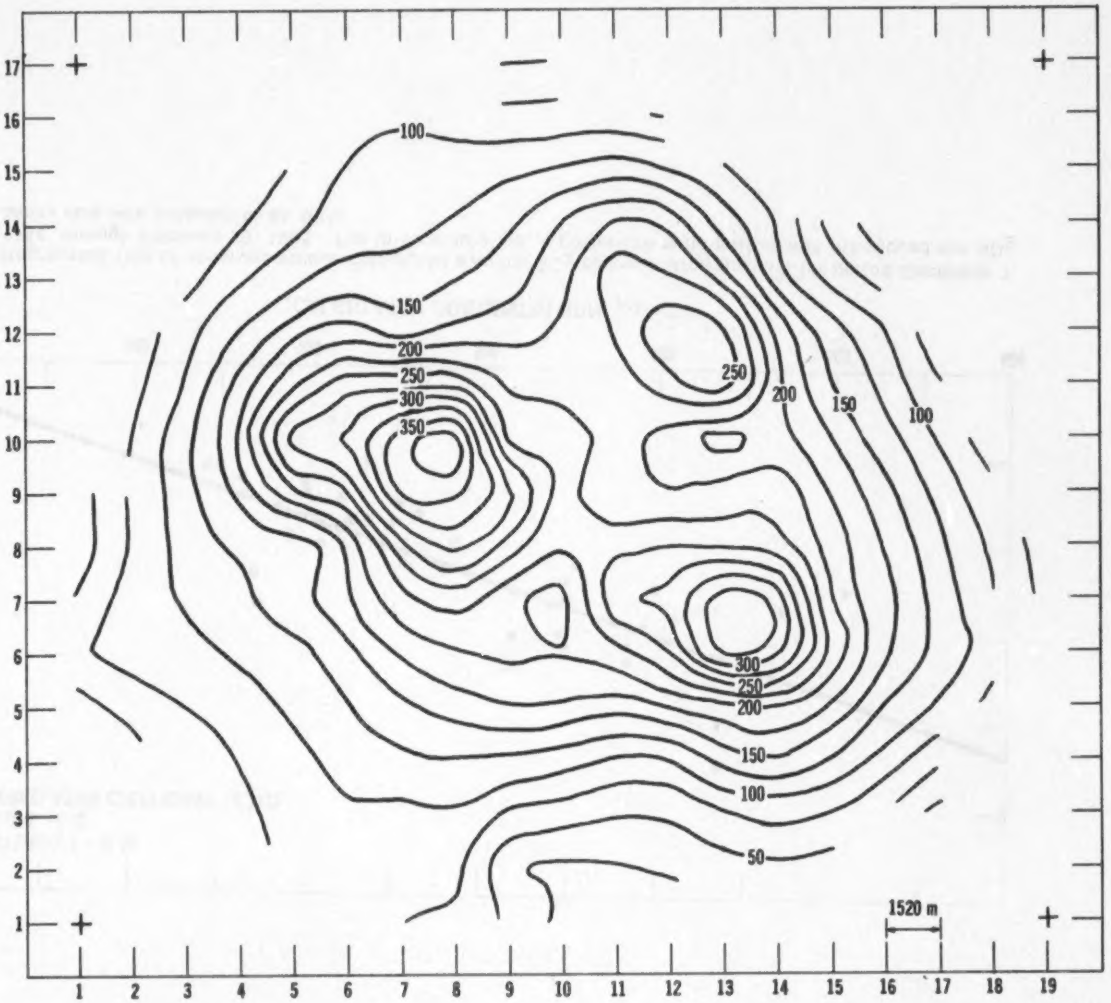
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Figure 6. Isopleths of computed average SO_2 concentration ($\mu g/m^3$) for period December 1, 1964, through February 28, 1965. For this calculation, wind speed was assumed constant with height and SO_2 half-life was assumed to be 30 minutes.

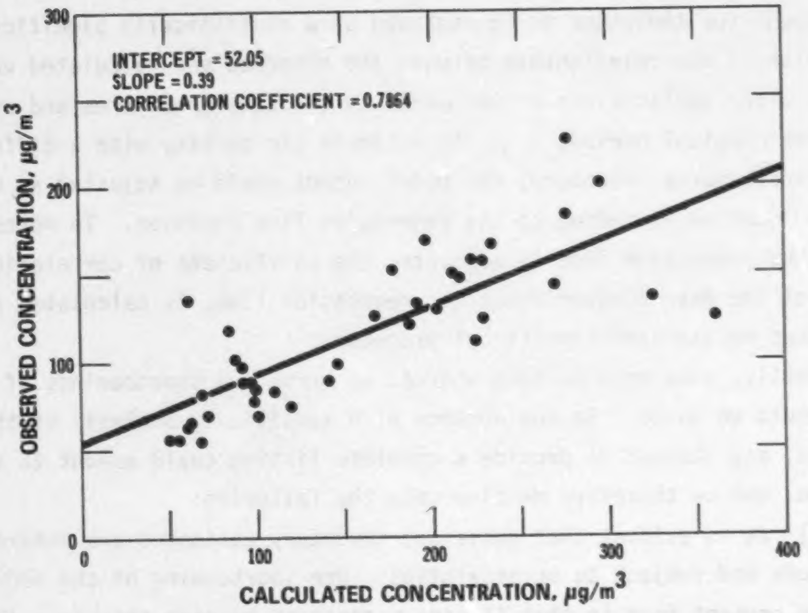

Figure 7. Regression line of observed versus calculated average SO_2 concentration ($\mu g/m^3$) for the period December 1, 1964, through February 28, 1965. For this calculation, wind speed was assumed constant with height and SO_2 half-life was assumed to be 30 minutes.

applications. Under these circumstances, the numerical properties, i.e., the relationship between model output and its numerous inputs, are only poorly understood. To improve understanding, the model is currently being subjected to an input-output sensitivity analysis.

The urgent practical need to apply the Martin-Tikvart model immediately and prior to further development and analysis has given rise, as an interim measure, to the concept of "calibrating" the model with observed air quality data (TRW Systems Group, 1969). As in the particular examples considered above for St. Louis, this involves determination of the least-squares regression line of observed concentration values on the values calculated by use of the model. If the scatter of points about the regression line is small enough for thelatter to be regarded as a statistically significant description of the relationship between the observed and calculated values, then, in other applications of the model to the same urban area and over the same climatological period, e.g., to estimate air quality with a different hypothetical source inventory, the model output would be adjusted at each receptor location according to the regression line equation. To determine whether the regression line is adequate, the coefficient of correlation, a measure of the data scatter about the regression line, is calculated and interpreted by standard statistical procedure.

Finally, some more obvious sources of error and shortcomings of the model should be noted. In the absence of a sensitivity analysis of the type mentioned, any attempt to provide a complete listing could amount to self-deception, and we therefore mention only the following:

(a) It is evident that emissions inventory estimates are inherently crude and subject to uncertainties. One shortcoming of the model in its present form is that it uses a constant average emissions inventory although significant variations must occur throughout the day, day-to-day and seasonally. The fact that the assumption of a diurnally constant emission rate may lead to overcalculation of concentrations has been previously noted by Clarke (1964) and Turner (1964), who indicated the need for a lower emission rate at night. That this is a source of overcalculation in the Martin-Tikvart model was demonstrated by some ad hoc calculations, although difficulty of developing a generally applicable objective scheme for specifying diurnal variability of emissions is apparent.

(b) The climatological data used in the model calculations must, in practice, frequently be obtained from a nearby airport weather station, and is a poor indication of urban meteorological conditions. Particular caution should be exercised in applying the model to any locales where the topography is at all complicated.

(c) The method proposed for estimating the mixing depth for use in the model calculations is very crude. Better modeling should result when data based on actual atmospheric soundings can be utilized. It is particularly desirable to refine the estimates of nighttime mixing depth as it may be shown, when the concentration calculations are separated by stability category, that the contribution from the nighttime stability category P_5 (when a 100 meter mixing depth is assumed) is frequently much greater than from all other stabilities even though P_5 only represents about 25% of the total observations.

REFERENCES

Bierly, E. W., and Hewson, E.W., 1962: Some restrictive meteorological conditions to be considered in the design of stacks. J. Appl. Meteorol., 1, 3, 383-390.

Briggs, G. A., 1969: Plume Rise. A.E. C. Critical Review Series, U.S. Atomic Energy Commission, Division of Technical Information

Calder, K. L., 1969: Some miscellaneous aspects of current urban pollution models. Symposium on multiple source urban diffusion models, Univ. of North carolina, Chapel Hill (To be published)

Clarke, J.F., 1964: A simple diffusion model for calculating point concentrations from multiple sources. APCA Journal, 14, 9, 347-352.

Clarke, J.F., 1969: Nocturnal urban boundary layer over Cincinnati, Ohio Monthly Weather Review, 97, 8, 582-589.

DeMarrais, G. A., 1959: Wind speed profiles at Brookhaven National Laboratory J. Appl. Meteorol., 16, 181-189.

Farmer, J.R., and Williams, J.D., 1966: Interstate Air Pollution Study, Phase II Project Report, III Air Quality Measurements, USDHEW, NAPCA, Cincinnati, Ohio.

Fortak, H., 1969: Numerical simulation of the temporal and spatial distributions of urban air pollution concentrations. Symposium on multiple source urban diffusion models, Univ. of North Carolina, Chapel Hill (To be published).

Gifford, F. A., 1961: Use of routine meteorological observations for estimating atmospheric dispersion. Nuclear Safety, 2, 4, 47-51.

Holland, J. Z., 1953: A meteorological survey of the Oak Ridge area. U.S. AEC Report ORO. 99, Tech.Inf. Serv., Oak Ridge, Tennessee.

Holzworth, G. C., 1967: Mixing depths, wind speeds, and air pollution potential for selected locations in the United States. J. Appl. Meteorol., 6, 6, 1039-1044.

Leavitt, J. A., 1960: Meteorological considerations in air quality planning. J. Air Poll. Contr. Assoc., 10, 3, 246-250.

Ozolins, G., and Smith, R., 1966: A Rapid Survey Technique for Estimating Community Air Pollution Emissions. U.S. Dept. of Health, Education, and Welfare, Public Health Service, National Air Pollution Control Administration, Raleigh, North Carolina, PHS Pub. No. 999-AP-29.

Pasquill, F., and Meade, P.J., 1958: A study of the average distribution of pollution around Staythorpe. Int. J. Air Poll., 1, 60-70.

Pasquill, F., 1961: The estimation of the dispersion of windborne material Meteorol. Mag., 90, 1063, 33-49.

Pasquill, F., 1962: Atmospheric Diffusion. Van Nostrand Co., New York.

Pooler, F., 1966: A tracer study of dispersion over a city. J. Air Poll. Contr. Assoc., 16, 12, 677-681.

Szepsi, D.J., 1967: A model for the long-term distribution of pollutants around a single source. IDOJARAS (Budapest), 68, 257-69.

Szepsi, D.J., 1967: Meteorological Conditions of the Turbulent Diffusion of Atmospheric Pollutants in Hungary. Official Publications of the National Meteorological Institute, Vol. 32, Budapest.

TRW Systems Group, 1969: Air Quality Display Model. Contract No. PH 22-68-60 USDHEW, Public Health Service, National Air Pollution Control Administration, Washington, D.C.

Turner, D.B., 1961: Relationship between 24-hr. mean air quality measurements and meteorological factors in Nashville, Tennessee. J. Air Poll. Contr. Assoc., 11, 483-489.

Turner, D.B., 1964: A diffusion model for an urban area. J. Appl. Meteorol., 3, 83-91.

Turner, D.B., and Edmisten, N.G., 1968: St. Louis SO_2 dispersion model study - Description of basic data (Unpublished report, Division of Meteorology, NAPCA).

Turner, D.B., 1969: Workbook of Atmospheric Dispersion Estimates. USDHEW PHS, National Air Pollution Control Administration, Cincinnati, Ohio, PHS Pub. No. 999-AP-26.

Weber, E., 1970: Contribution to the residence time of sulfur dioxide in a polluted atmosphere. J. Geophys. Res., 75, 15, 2909-2914.

APPENDIX E:

AN EVALUATION OF SOME CLIMATOLOGICAL DISPERSION MODELS

by

D.B. Turner, J.R. Zimmerman, and A.D. Busse

On assignment from
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

Division of Meteorology
National Environmental Research Center
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

Paper presented at

Third Meeting of the NATO/CCMS Panel on Modeling

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AN EVALUATION OF SOME CLIMATOLOGICAL DISPERSION MODELS

by

D. Bruce Turner*, John R. Zimmerman*, and Adrian D. Busse*

ABSTRACT

Six different dispersion models were used in a climatological mode of application with point source and area emission data to calculate annual (1969) sulfur dioxide and total suspended particulate matter for the New York Air Quality Control Region. Two of the models, the Air Quality Display Model and the Climatological Dispersion Model, use joint frequency distributions of wind direction, wind speed, and stability class as meteorological data. The Climatological Dispersion Model (single stability) requires only a wind direction frequency and harmonic mean speed for each direction. The other three models: Gifford '72, Modified Hanna, and Modified Hanna Including Source Height; require only mean annual wind speeds for climatological application.

Simple models are as highly correlated with measurements as are the more complex models, explaining 70% of the sulfur dioxide variance and 40% of the particulate variance. For SO_2, root mean square errors for the best complex model are 52; those for the simple models are 56 to 59. The standard deviation of the measurements is 72. For particulates, root mean square errors for the complex model are 16; those for the simple models are 19 to 40. The standard deviation of the measurements is 23.

It is difficult to achieve results surpassing those of the simple models. Of the two more complex models, the AQDM and the CDM, the CDM yields smaller errors with means and maxima nearer those of the measurements. Evaluation of models should include comparison of results with those from simple models applied to the same data.

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*On Assignment from the National Oceanic and Atmospheric Administration, Department of Commerce

INTRODUCTION

Six different dispersion models were used to calculate annual (1969) sulfur dioxide and total suspended particulate matter for the New York Air Quality Control Region. Two of the models, the Air Quality Display Model and the Climatological Dispersion Model, use joint frequency distributions of wind direction, wind speed, and stability, as meteorological data. The Climatological Dispersion Model applied for a single stability requires only a wind direction frequency and harmonic mean speed for each direction. The other three models based upon ideas of Gifford and Hanna (1971, 1972) require only mean annual wind speeds for climatological application. These are referred to as: Gifford '72, Modified Hanna, and Modified Hanna Including Source Height.

The emission inventory, measured air quality data, meteorological data, and climatological estimates of pollution concentration using the Air Quality Display Model were obtained from EPA's Air Quality Management Branch. Emission estimates for 1969 for both pollutants for 854 area sources varying in size from 1 km^2 to 100 km^2, and for 674 point sources were included. Estimates of stack height, stack diameter, stack gas exit velocity, and stack gas temperature were also included for the point sources. A stability wind rose (joint frequency distribution of wind direction, wind speed, and stability class) was available for La Guardia Airport based on the 3-hourly observations during 1969. These observations are routinely available in computer compatible form (punch cards or magnetic tape).

Each of the models was used to calculate mean annual concentrations of sulfur dioxide at 75 locations and total suspended particulate matter at 113 locations. These estimates were compared with mean annual concentrations based upon measurements.

DESCRIPTION OF MODELS

1. Air Quality Display Model (AQDM)

The AQDM, a climatological model based on ideas of Martin and Tikvart (TRW Systems Group, 1969; Martin and Tikvart, 1968; and Martin, 1971), considers the joint frequency distribution of wind direction to 16 points, wind speed in 6 classes, and stability categories in 5 classes. Computations for a receptor point are made by considering the contribution of each point and area source to this receptor. Separate calculations are made for each speed class - stability class combination for the wind direction sector about the receptor that contains the source. For area sources a modification of the virtual point source method is used. Estimation of area source heights are assumed to be effective height of the area source. The effective height can be different for each area source. Holland's plume rise equation (Holland, 1953) is used to estimate the effective height of point sources. A feature of the AQDM is that a source contribution file consisting of the partial concentration of each receptor due to each point and area source is retained at the end of the computation. This is primarily used as input to control strategy studies.

2. Climatological Dispersion Model (CDM)

The CDM described in detail by K. L. Calder (1971) has been applied to air quality estimates for Ankara, Turkey, and St. Louis (Zimmerman, 1971, 1972) for the Committee on Challenges of Modern Society. Although similar in many respects to the AQDM, the CDM contains several distinct features. In the CDM, area sources are calculated using the narrow plume hypothesis (Gifford and Hanna, 1971) applied for winds within a sector (Calder, 1971) which involves an upwind integration over the area sources. Emission rates at various upwind distances, using an expanding scale, are averaged over an arc within the sector. A power law for the vertical wind profile which is a function of stability is used to extrapolate surface winds to the source height. Estimation of effective height of point sources is by Briggs plume rise (Briggs, 1969). The total concentration at each receptor is the sum of 32 concentrations. These concentrations are those from point and from area sources for each of the 16 wind directions. These values are retained and are useful in plotting direction contribution pollution roses. The running time of the CDM is about 73% of that required by the AQDM.

3. Climatological Dispersion Model (Single Stability)

Whereas both the AQDM and the CDM are applied for 5 different stabilities and 6 wind speed classes within each stability class, this model performs the calculations for a single stability and further reduces the computations by using a single wind speed for each of the 16 wind direction sectors. The single wind speed is a harmonic mean of the average speed for each wind speed class weighted for its frequency. The running time of this single stability version of the CDM is about 30% of that required by the CDM.

4. Gifford '72

Drs. Frank Gifford and Steve Hanna of NOAA's Atmospheric Turbulence and Diffusion Laboratory in Oak Ridge, Tennessee, have been active in developing simple dispersion models for estimating concentrations (Gifford and Hanna, 1971; Hanna, 1971). In a recent manuscript (Gifford and Hanna, 1972), they have suggested use of

$$\chi_A = C \frac{\bar{q}}{\bar{u}} \qquad (1)$$

where χ_A is the concentration in $\mu g m^{-3}$ of the pollutant of interest due to all area sources for a particular averaging time, C is a dimensionless constant, $\bar{q}$ is an average area emission rate in $\mu g m^{-2} sec^{-1}$ in the vicinity of the receptor, and $\bar{u}$ is the mean wind speed in m sec^{-1}. Both $\bar{q}$ and $\bar{u}$ are for the same averaging time as the concentration, χ_A. They suggest that the values of C are 50 for sulfur dioxide and 225 for particulate matter. Concentrations at this receptor from point sources for the same averaging time should be added to the concentrations from area sources. These can be determined from an appropriate point source model. Without firm direction from the manuscript of Gifford and Hanna as to what area about the receptor should be used to obtain average area emissions, the authors selected an area after an investigation which will be described later.

5. and 6. Modified Hanna

Since emissions close to a receptor at about the same height as the receptor have a greater influence than emissions at greater distances, it was felt that an improvement to the above Gifford '72 model could be made which would eliminate the use of the rather arbitrary constant C, and would also eliminate the difficulty of not knowing just which area should be considered in determination of the average area emission rate. The model can be expressed as:

$$x_A = \frac{1}{\bar{u}} \sum_i k_i \bar{q}_i + b \qquad (2)$$

where i is an index referring to a range of distances from the receptor, $\bar{q}_i$ is the average area emission rate for this range of distance about the receptor, $\bar{u}$ is mean wind speed as before, b is background concentration of the pollutant considered beyond the last distance considered in the summation, and the coefficient, k, is determined from:

$$k_i = \int_{x_l}^{x_u} \frac{2}{\sqrt{2\pi}\ \sigma_z} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] dx \qquad (3)$$

where x_l and x_u are the lower and upper limits of distance of the i^{th} range, σ_z is a dispersion parameter dependent upon distance and representative of mean stability conditions for the period of interest, H is a single effective height of emission for the pollutant considered for area sources in the region under consideration. In general, the value of b will be the concentration of the particular pollutant at the boundaries of the region considered, i.e., the boundary of the emission inventory. Note that the k's are dependent only upon the mean meteorological conditions and the height of emission and, therefore will be constant for a given distance range, and independent of receptor location. On the other hand, the $\overline{q_i}$'s are determined for different distance ranges about each receptor and, therefore, are dependent upon receptor location.

Model 5, referred to as the Modified Hanna, is applied with H=0. This is the same in concept as that of Steve Hanna (1971). The only difference is that in this model sources are considered for ranges of distance without regard to direction variations. For this model the values of k can be determined analytically.

Model 6, referred to as the Modified Hanna Including Source Height, uses a mean value of effective height of emission for each pollutant. For this case the values of k are determined by numerical integration.

Both Models 5 and 6 can be considered as further simplifications to the CDM and CDM (single stability) models since another liberty has been taken, that of calculating emissions for various distance ranges instead of in each wind direction sector.

APPLICATION OF THE MODELS TO THE NEW YORK REGION

With each of the models, calculations of ground level concentrations of both sulfur dioxide and total suspended particulate matter were made. Measurements of sulfur dioxide were available at 75 locations and of particulate matter at 113 locations.

As indicated, the AQDM was applied to the data for this area by the Air Quality Management Branch. A background of 35 μgm^{-3} was added to each calculated value of particulate concentration before comparing with measurements. A background of 35 was also added to each calculated value of particulate matter by the CDM before comparing with the measurements.

For applying the CDM for a single stability, Table 1 lists the frequencies and the harmonic mean wind speeds for each direction. The model was applied for three different single stabilities. The values used for the σ_z parameter most closely approximate those corresponding

TABLE 1

Frequencies and Harmonic Mean Wind Speeds for Each Direction

SECTOR	$f(\theta)$	$\bar{u}(\theta)$ (m sec^{-1})
NNE	0.088	3.65
NE	0.054	2.98
ENE	0.076	3.27
E	0.084	3.53
ESE	0.036	2.82
SE	0.010	2.04
SSE	0.014	2.78
S	0.025	3.54
SSW	0.117	4.00
SW	0.044	2.93
WSW	0.062	3.27
W	0.075	3.72
WNW	0.071	4.73
NW	0.086	4.43
NNW	0.082	3.90
N	0.075	4.12

TABLE 2

Dispersion Parameter Coefficients and Exponents

$$\sigma_z = a\,x^b$$

Range of x (meters)	C Stability		C/D Stability		D Stability	
	a	b	a	b	a	b
<500	0.1120	0.9100	0.1078	0.87645	0.0856	0.8650
500-5000	0.1014	0.9260	0.1725	0.80072	0.2591	0.6869
>5000	0.1154	0.9109	0.3546	0.71611	0.7368	0.5642

to Pasquill's C, D, and something between C and D (Pasquill, 1962; Turner, 1967) so the notation: C, D, C/D is used to designate these. The coefficients and exponents for various downwind distances from the source, x, for these three stabilities used to determine σ_z from:

$$\sigma_z = ax^b \tag{4}$$

are given in Table 2.

For application of the Gifford '72 model, the mean wind speed for La Guardia Airport for the year 1969 as given by the Local Climatological Data (Environmental Science Service Administration, 1969) of 11.6 miles per hour (5.1852 m sec^{-1}) was used. As indicated, Gifford (1972) is not clear as to the size of the area that should be considered for averaging area emission rates. Therefore, three distances were selected: 3, 5, and 10 km. Using the emission rates for the area sources on the 1 km basis previously prepared as part of the CDM run, a computer calculation was made to determine average emissions for both SO_2 and particulate within circles centered on each receptor for radii corresponding to the three above-mentioned distances. If the center of a 1 km source square was within the circle, it was included in the averaging; if the center was outside, it was not included. After determining the average emission rate for the three different radius circles, the linear correlation coefficient of measurements of concentration as a function of average emission rate was determined for both pollutants. This appears on the left side of Table 3. From these results, the average emission rates for circles with a radius of 10 km were selected for use in applying the Gifford '72 model. At a later time the average emissions for larger circles and the corresponding correlation coefficients were determined. These appear in the right hand portion of Table 3.

Since Gifford indicates that the values of the factor C of 50 for sulfur dioxide and 225 for particulate matter were determined without consideration of any background values, no background was added to the estimates from this model before comparing with measurements. Comparisons of this model were made with measurements for both: estimates from area sources only, and estimates from the area sources using this model with estimates of concentration due to point sources as determined from the CDM model added to the area estimates. (After noting the results achieved with this model, a background of 35 was added for particulate matter estimates for an additional comparison.)

In applying the Modified Hanna Model to this region, six ranges of distances were used as shown in Table 4. From intermediate results punched on cards during the determination of the average emission rates for various sized circles, it was simple to determine the average emission rates for the 5 annular areas. For application of the Modified Hanna Including Source Height (Model 6), the average emission heights

TABLE 3

Linear Correlation Coefficients of Measured Air Quality Data with Average Emission Rate of Circles of Given Radius about Each Receptor

Pollutant	Number of Receptors	Radius of Emission Area (km) 3	5	10	20	30	40
Sulfur dioxide	75	0.73	0.79	0.81	0.85	0.78	0.70
Particulate matter	113	0.61	0.64	0.63	0.63	0.63	0.60

TABLE 4

Limits of Integration and Corresponding Values of k from Equation (3)

i	x_l km	x_u km	k_i Model 5 $H = 0$	Model 6 $H = 10$ Particulate	$H = 30$ SO_2
1	0	3	163.468	50.331	30.715
2	3	5	12.264	12.133	11.844
3	5	10	19.344	19.183	18.993
4	10	20	23.551	23.053	22.973
5	20	30	16.085	15.580	15.555
6	30	40	12.589	12.120	12.110

of 30 meters for sulfur dioxide and 10 meters for particulate matter were chosen as representative of effective heights of emission for the New York region. (One could apply this model using different effective heights of emission for various receptor locations, but only one height for each pollutant was used here.) Using values of the dispersion parameter, σ_z, corresponding to C/D stability the k_i's were determined by integrating analytically over appropriate distance ranges for use in Model 5 and using the σ_z's for C/D stability and the above emission heights, numerical integrations were performed to determine the values of the factors, k_i for use with Model 6. These are also shown in Table 4. Values of background concentration, b, of 0 and 35 were used for sulfur dioxide and particulate matter respectively in equation (2).

STATISTICS USED FOR EVALUATION

To evaluate the various models, 12 different statistics were used. One of these was the mean concentration for all stations. Considering the error for each location to be defined as the calculated concentration from the model minus the measured concentration, the root mean square error and the mean absolute error were determined. As an indication of the range of errors at the individual measurement locations, the largest negative error (underestimate), the largest positive error (overestimate), and the range of errors (the largest positive error minus the largest negative error) were tabulated. Linear correlation coefficients, the variance of the correlation (the square of the correlation coefficient) and the slope and intercept of the least squares line of regression between model estimates and the measured values were also calculated.

Because of its importance to the meeting of air quality standards, the error at the location with the highest measured concentration is of interest as well as the maximum estimated concentration at any of the measuring station locations.

RESULTS

The results of the comparison of model estimates with measurements are given in Table 5 for sulfur dioxide and in Table 6 for particulates. In addition to comparing the calculated AQDM estimates with measurements, the Air Quality Management Branch had used the measured air quality data to calibrate the AQDM. Considering the calculations without background as the independent variable, the measurements as the dependent variable, least square lines that are forced to have an intercept of 0 for sulfur dioxide and 35 for particulate matter were determined. The slope and intercepts for these lines are given in Table 7. Using the equations of these lines, "calibrated" concentration estimates were determined from the calculated concentrations. This was done similarly for all other models. The comparisons of these estimates with the

MAX MEAS = 350

TABLE 5. NEW YORK - SULFUR DIOXIDE

	MEAN (MEAS =135)	NUM BER	RMSE (STD DEV OF MEAS =72)	MEAN ABSOLUTE ERROR	LARGEST NEGATIVE ERROR	LARGEST POSITIVE ERROR	ERROR RANGE	LINEAR CORREL. WITH MEAS.	VARI- ANCE	SLOPE	INTER- CEPT	ERROR AT POINT OF MAXIMUM MEAS.	MAXIMUM ESTIMATED CONC. AT A MEAS. POINT
1 AIR QUALITY DISPLAY MODEL (AQDM)	211 (116)	75 (75)	121 (37)	92 (28)	-87 (-117)	310 (74)	397 (191)	0.89 (0.89)	0.79 (0.79)	0.45 (0.82)	31 (31)	112 (-97)	566 (310)
2 CLIMATOLOGICAL DISPERSION MODEL (CDM)	138 (115)	75 (75)	52 (44)	37 (32)	-118 (-143)	166 (121)	284 (264)	0.84 (0.84)	0.70 (0.70)	0.66 (0.79)	35 (35)	-101 (-143)	368 (307)
3 CDM (SINGLE STABILITY) 3A CDM (D STABILITY)	206 (112)	75 (75)	124 (45)	89 (33)	-112 (-153)	332 (114)	444 (267)	0.84 (0.84)	0.71 (0.71)	0.41 (0.76)	40 (40)	13 (-153)	577 (313)
3B CDM (C STABILITY)	94 (101)	75 (75)	56 (55)	46 (45)	-128 (-122)	96 (118)	224 (240)	0.82 (0.82)	0.67 (0.67)	0.73 (0.68)	56 (56)	-119 (-101)	307 (329)
3C CDM (C/D STABILITY)	139 (107)	75 (75)	64 (49)	45 (39)	-115 (-125)	188 (109)	303 (234)	0.84 (0.84)	0.70 (0.71)	0.55 (0.72)	49 (48)	-56 (-125)	423 (324)
4 GIFFORD '72 4A AREA ONLY	54 (91)	75 (75)	82 (63)	72 (54)	-175 (-151)	29 (125)	204 (276)	0.81 (0.81)	0.66 (0.66)	1.07 (0.63)	67 (67)	-175 (-54)	180 (304)
4B WITH CDM POINT ESTIMATES	79 (107)	75 (75)	59 (48)	50 (38)	-137 (-118)	49 (115)	186 (233)	0.85 (0.85)	0.72 (0.72)	0.97 (0.72)	48 (48)	-137 (-64)	219 (294)
5 MODIFIED HANNA 5A AREA ONLY	279 (77)	75 (75)	330 (77)	178 (65)	-145 (-152)	1232 (188)	1377 (340)	0.77 (0.77)	0.60 (0.60)	0.16 (0.58)	80 (80)	1153 (63)	1503 (413)
5B WITH CDM POINT ESTIMATES	305 (81)	75 (75)	348 (73)	193 (61)	-120 (-145)	1270 (189)	1390 (334)	0.78 (0.78)	0.62 (0.62)	0.16 (0.60)	76 (76)	1191 (62)	1541 (412)
6 MODIFIED HANNA INCL. SOURCE HEIGHT 6A AREA ONLY	102 (96)	75 (75)	58 (57)	45 (46)	-151 (-151)	190 (170)	341 (321)	0.84 (0.84)	0.71 (0.71)	0.62 (0.66)	62 (62)	49 (26)	399 (376)
6B WITH CDM POINT ESTIMATES	127 (105)	75 (75)	56 (48)	38 (37)	-126 (-131)	225 (157)	351 (288)	0.86 (0.86)	0.74 (0.74)	0.59 (0.71)	50 (50)	87 (11)	437 (361)

TABLE 6. NEW YORK - PARTICULATE MATTER

MAX MEAS = 169

	MEAN (MEAS = 82)	NUMBER	RMSE (STD DEV OF MEAS =23)	MEAN ABSOLUTE ERROR	LARGEST NEGATIVE ERROR	LARGEST POSITIVE ERROR	ERROR RANGE	LINEAR CORREL. WITH MEAS.	VARIANCE	SLOPE	INTERCEPT	ERROR AT POINT OF MAXIMUM MEAS.	MAXIMUM ESTIMATED CONC. AT A MEAS. POINT
1 AIR QUALITY DISPLAY MODEL (AQDM)	102 (77)	113 (113)	36 (21)	28 (15)	-51 (-60)	115 (54)	166 (114)	0.62 (0.63)	0.39 (0.39)	0.38 (0.62)	43 (34)	5 (-48)	199 (136)
2 CLIMATOLOGICAL DISPERSION MODEL (CDM)	74 (76)	113 (113)	22 (22)	16 (15)	-63 (-62)	68 (74)	131 (136)	0.61 (0.61)	0.37 (0.37)	0.63 (0.59)	35 (37)	-48 (-43)	135 (141)
3 CDM (SINGLE STABILITY) 3A CDM (D STABILITY)	88 (74)	113 (113)	28 (22)	21 (17)	-60 (-67)	98 (65)	158 (132)	0.64 (0.64)	0.41 (0.40)	0.42 (0.57)	45 (40)	-6 (-39)	165 (132)
3B CDM (C STABILITY)	58 (69)	113 (113)	31 (28)	26 (21)	-78 (-74)	59 (104)	137 (178)	0.57 (0.57)	0.32 (0.32)	0.69 (0.46)	42 (50)	-71 (-40)	126 (171)
3C CDM (C/D STABILITY)	69 (71)	113 (113)	25 (25)	19 (19)	-73 (-72)	75 (82)	148 (154)	0.61 (0.61)	0.37 (0.37)	0.54 (0.50)	45 (46)	-43 (-37)	142 (149)
4 GIFFORD '72 4A AREA ONLY	40 (64) (75)	113 (113) (113)	53 (30) (33)	47 (24) (27)	-117 (-83) (-82)	46 (42) (81)	163 (125) (163)	0.63 (0.63) (0.63)	0.40 (0.40) (0.40)	0.35 (0.47) (0.35)	68 (51) (56)	-56 (-50) (-21)	151 (147) (186)
4B WITH CDM POINT ESTIMATES	51 (68) (86)	113 (113) (113)	47 (27) (36)	40 (21) (28)	-111 (-79) (-76)	59 (38) (94)	170 (117) (170)	0.63 (0.63) (0.63)	0.40 (0.40) (0.40)	0.32 (0.49) (0.32)	65 (48) (54)	-44 (-52) (-9)	164 (143) (199)
5 MODIFIED HANNA 5A AREA ONLY	80 (62)	113 (113)	41 (31)	30 (25)	-77 (-81)	177 (80)	254 (161)	0.64 (0.64)	0.40 (0.40)	0.28 (0.47)	59 (53)	61 (-16)	281 (184)
5B WITH CDM POINT ESTIMATES	92 (66)	113 (113)	45 (28)	32 (22)	-71 (-78)	190 (74)	261 (152)	0.64 (0.64)	0.40 (0.40)	0.27 (0.48)	57 (50)	73 (-20)	294 (178)
6 MODIFIED HANNA INCL. SOURCE HEIGHT 6A AREA ONLY	56 (66)	113 (113)	31 (28)	26 (22)	-80 (-77)	25 (68)	105 (145)	0.66 (0.66)	0.43 (0.43)	0.72 (0.49)	41 (49)	-58 (-23)	129 (172)
6B WITH CDM POINT ESTIMATES	67 (73)	113 (113)	25 (24)	19 (18)	-71 (-69)	37 (55)	108 (124)	0.62 (0.62)	0.39 (0.39)	0.63 (0.54)	39 (42)	-53 (-39)	141 (159)

TABLE 7

Equations of Least Squares Lines (y=a+bx) Used to Determine Calibrated Concentrations

Model	Sulfur Dioxide		Particulate Matter	
	b	a	b	a
1. AQDM	0.5478	0	0.6162	35
2. CDM	0.8330	0	1.0630	35
3a. CDM (D Stability)	0.5429	0	0.7452	35
3b. CDM (C Stability)	1.0790	0	1.4956	35
3c. CDM (C/D Stability)	0.7653	0	1.0637	35
4. Gifford '72				
A. Area only	1.6909	0	0.7430	35
B. With CDM point estimates	1.3435	0	0.6557	35
5. Modified Hanna				
A. Area only	0.2746	0	0.6063	35
B. With CDM point estimates	0.2676	0	0.5512	35
6. Modified Hanna Including Source Height				
A. Area only	0.9435	0	1.4594	35
B. With CDM point estimates	0.8265	0	1.1717	35

measured concentrations are reported in Tables 5 and 6 in parentheses with each model. Note that the "calibrated" estimates are compared with the same measurements used for determining the calibration equations, not with independent data. Although the development of the coefficients for the Gifford '72 should not require the addition of a background concentration, the estimated values from this model were also tested after adding a background of 35 μgm^{-3} to the particulate values. These results are reported in brackets in Table 6.

Models 1 and 2 (both AQDM and CDM) each require joint frequency distributions of wind direction, wind speed, and stability. For the CDM (single stability) only the frequency and mean speed for each direction (Table 1) are required. For the last three models only the mean annual wind speed is used although the effects of the point sources, that are added in, have used the joint frequency distribution information.

Considering first the results for sulfur dioxide, for the mean concentration for the 75 locations, Model 2 with 138, Model 3c with 139, and Model 6 b. with 127 are all close to the mean of measurements of 135 μgm^{-3}. Note that calibration causes all models to underestimate the mean. For the root mean square error, Model 2 with 52, Models 3b and 6b with 56 are examples. Six of the 11 models have a RMSE less than the standard deviation of the measured values, 72 μgm^{-3}.

As expected, calibration reduces the root mean square error but in some cases only slightly. The smallest mean absolute errors are from Model 2 with 37 and Model 6 b with 38. Calibration reduces the mean absolute error. The range of errors is lowest, 186 (-131 to 49), for Model 4 b. Note that all correlations are quite close, ranging from 0.77 to 0.89. The error at the point of the maximum measurement varies from an underestimate of 175 μgm^{-3} to an overestimate of 112 μgm^{-3}, ignoring the huge overestimates of Model 5. Model 3 a. with an overestimate of 13 μgm^{-3} has the least error. Calibration causes Model 6 b's overestimate of 11 μgm^{-3} to be smallest. The maximum estimated concentration at a measurement point ranges from 180 μgm^{-3} to 577 μgm^{-3} (again ignoring Model 5) with Model 2's estimate of 368 closest to the measured maximum of 350 μgm^{-3}. Calibration improves some estimates of the max, notably Model 6 b. with 361.

In the results for the particulate matter (Table 6) for the mean concentration, the 80 μgm^{-3} from Model 5 a is closest to the mean of all measurements of 82. Models 3a, 2, and 5b also are close. Calibration improves the means from most of the models. For the root mean square error, only Model 2 with 21 is less than the standard deviation of measured particulate values of 23 μgm^{-3}. With calibration, Models 1, 2, and 3a have RSME less than 23. For the mean absolute error, Model 2 with 16 μgm^{-3} is the smallest. With regard to the largest errors, the models are not greatly different if Model 5 is excluded. Model 2 has the smallest error range, 131. Generally calibration doesn't have too much effect on the range of errors. The correlations are not greatly different for the various models ranging from 0.57 to 0.66 although they are poorer than those for SO_2. The variance is about half those for SO_2: 0.32 to 0.43 for particulate, 0.60 to 0.79 for SO_2. This may be due, in part, to the difficulty in obtaining a reliable emission inventory for particulate matter and in obtaining representative measurements. The error at the point of maximum concentration is a slight overestimate of 5 μgm^{-3} for Model 1 and a slight underestimate of 6 μgm^{-3} for Model 3a. For the maximum concentration at any measurement point, Model 3a with 165 and Model 4b. with 164 are near the maximum measured at any sampling station of 169. Generally, calibration does not greatly improve the estimate of the maximum. An exception is Model 3b. whose calibrated maximum is 171.

CONCLUSIONS

There is no one model that is superior in all statistics. The AQDM (Model 1) overestimates concentrations. Although we feel that the use of the Holland plume rise equation contributes to this overestimation, it is not the only cause. Many measurements of air quality are needed in order to calibrate the AQDM. This results in a low error but also, in this case, results in underestimated concentrations for both the mean and the maximum.

The CDM (Model 2) gives a good estimate of the mean and maximum for SO_2 in this test, but somewhat underestimates the particulate concentrations, particularly the maximum. It should be noted that this is without a calibration, therefore no extensive measurement network was required to obtain the result.

The CDM (single stability) with the dispersion parameters given by the C - D stability class (model 3c) gives a better estimate of the mean of all stations than of the other statistics. The errors are somewhat larger than the full model. Like the CDM Model, the CDM (C/D stability) overestimates the SO_2 maximum concentration but underestimates the particulate concentration.

The Gifford '72 Model underestimates both the mean concentrations and also the maximum SO_2 but produces a good estimate of the particulate maximum for this test region. Although the errors are somewhat larger than with the other models, they are not greatly different considering the degree of simplicity of this model over the preceding ones. The addition of a background of 35 μgm^{-3} for the particulate estimates improves the results of this model in most statistics with the exception of the maximum concentration at any measurement point.

The Modified Hanna Including Source Height seems to be an improvement over the Gifford '72 Model with regard to means and errors but does not perform as well on the maxima, overestimating SO_2 and underestimating particulate. Note that there is a relatively close correspondence between the CDM (C/D stability) and Model 6b in nearly all statistics and for both pollutants.

Simple models using only mean annual wind speeds and emissions do quite well compared to the more complex models. The input and the calculations are simple. They do have limitations when trying to use the results to apply control strategies. For the simple models at each receptor there are two concentration estimates available: that due to point sources and that due to area sources. Of the more complex models (1 and 2), these data indicate a preference for the CDM over the AQDM.

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REFERENCES

Briggs, G. A., 1969: Plume Rise. AEC Critical Review Series. Oak Rdige, Tenn., USA, Atomic Energy Commission, Division of Technical Information, 81 p. (Available from NTIS as TID-25075)

Calder, Kenneth L., 1970: Some miscellaneous aspects of current urban pollution models. Proc. of Symposium on Multiple-Source Urban Diffusion Models, 13 p. US Envir. Prot. Agency Air Pollution Control Office Pub. No. AP-86.

Calder, Kenneth L., 1971: A climatological model for multiple source urban air pollution. Proc. 2nd Meeting of the Expert Panel on Air Pollution Modeling, NATO Committee on the Challenges of Modern Society, Paris, France, July 1971, 33 p.

Environmental Science Services Administration, 1969: Local climatological data, New York, N. Y., La Guardia Airport.

Gifford, F. A., Jr., and Hanna, Steven R., 1971: Urban air pollution modeling. Proc. 2nd International Clean Air Congress. Edited by H. M. Englund and W. T. Berry, Academic Press, New York and London, 1146-1151.

Gifford, F. A., Jr., and Hanna, S. R., 1972: Modeling urban air pollution. Atmos. Environ. in press.

Hanna, Steven R., 1971: A simple method of calculating dispersion from urban area sources. J. Air. Poll. Contr. Assoc., 21, 12, 774-777.

Holland, J. Z., 1953: A meteorological survey of the Oak Ridge area. 554-559, Atomic Energy Comm., Report ORO-99, Washington, D. C., 584 p.

Martin, Delance O., 1971: An urban diffusion model for estimating long term average values of air quality. J. Air Poll. Contr. Assoc., 21, 1, 16-19.

Martin, Delance O., and Tikvart, Joseph A., 1968: A general atmospheric diffusion model for estimating the effects of air quality of one or more sources. APCA Paper 68-148, Presented at 61st annual APCA meeting, St. Paul Minn., June 1968.

Pasquill, F., 1962: Atmospheric Diffusion. London, D. Van Norstrand, 297 p.

TRW Systems Group, 1969: Air quality display model. Prepared for Department of Health, Education, and Welfare, Public Health Service, Consumer Protection and Environmental Health Service, National Air Pollution Control Administration, Washington, D. C., Contract No. Ph-22-68-60. (Available from NTIS, Springfield, Va., 22151 as PB-189-194)

Turner, D. B., 1967: Workbook on atmospheric dispersion estimates. National Air Pollution Control Administration, Cincinnati, Ohio, PHS Pub. No. 999-AP-26, 84 p.

Zimmerman, John R., 1971: Some preliminary results of modeling from the air pollution study of Ankara, Turkey. Proc. 2nd Meeting of the Expert Panel on Air Pollution Modeling, NATO Committee on the Challenges of Modern Society, Paris, France, July 1971, 28 p.

Zimmerman, John R.,1972: The NATO/CCMS air pollution study of St. Louis, Missouri. To be presented at 3rd Meeting of the Expert Panel on Air Pollution Modeling, NATO Committee on the Challenges of Modern Society, Paris, France, October 1972.